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ORDINARY MEETING.

21 January, 1941.

Sir LEOPOLD HALLIDAY SAVILE, K.C.B, President, in the Chair.

The PRESIDENT referred to the death of Sir Harley Dalrymple-Hay, and it was accordingly resolved :—

> That the members present at this Ordinary Meeting record the deep regret with which they have learned of the death of Sir Harley Hugh Dalrymple-Hay, who had been a Member of the Council since 1933 ; and that an expression of their sincere sympathy be conveyed to the members of his family.

The Council reported that they had recently transferred to the class of

Members.

RONALD WILFRID BATEMAN, B.Sc. (Eng.) (*Lond.*).
Sir ARROL MOIR, *Bart.*, B.A. (*Cantab.*).

And had admitted as

Students.

CANDIAH ALAGARATNAM.
ARVIND SHANKAR BAM, B.Sc. (*Bombay*).
PATRICK CHARLES BARR.
COLIN STRACHAN BEATTIE.
DONALD CASEBOURNE.
DONALD HENRY COSWAY, B.Sc. (*Bristol*).
PAUL LOUIS DE VALENCE.
KENNETH GEORGE DURSTON.
FRANKIS ALAN FISHER.
TOM GRAY.
CHARLES WILLIAM HARVEY.
THOMAS HAROLD HUGHES.
ROY ALAN KLAPKA.
THOMAS WALTER LENG.
PETER GEORGE MACKAY.
SEAGHAN MACKEY, B.Sc., B.E. (*National*).
GEORGE FRANCIS MORT.
ISAAC WALLACE NEIL.
JOHN CUTHBERT PARDOE.
WILLIAM PHILLIPS, B.Sc. (Eng.) (*Lond.*).
PENUMATCHA VENKATAPATHI RAJU, B.E. (*Madras*).
STANLEY REX ROBSON.
KENNETH JOHN RODGER.
PETER DOUGLAS ROWDEN.
PETER CECIL SALISBURY.
GEORGE CUMMING STAINTON.
ERIC BONE THOMSON.
THOMAS JOHN UPSTONE, B.Sc. (*Bristol*).
COLIN VEYSEY.
KENNETH TOMALIN WATSON.
NORMAN MONTAGUE WHITE.
IAN HENDERSON WILLIAMS.

The Scrutineers reported that the following had been duly elected as

Associate Members.

Sydney Charles Baker.
Douglas Wilfred Blackmore.
Kenneth Bolton, B.Sc. (*Leeds*).
Geoffrey Cyril Raymond Carey, B.Sc. (*Belfast*), Stud. Inst. C.E.
William Roy Champion.
Ernest John Chesterman.
Alfred Edward Chittenden, B.Sc. (Eng.) (*Lond.*).
William Barnard Clark.
David Alexander Fleming Colville, B.Sc. (*Edin.*), Stud. Inst. C.E.
Brian Charles Alfred Cox, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
James Arthur Dodworth, Stud. Inst. C.E.
Dermot Joseph Doyle, B.E. (*National*).
Josiah Eccles, B.Sc. (*Belfast*).
Hassan Fahmy El-Baroudy, Ph.D. (Eng.) (*Lond.*).
Ronald Harold Eveleigh.
John Sithern Henzell, B.Sc. (Eng.) (*Lond.*).
Edward Townsend Hippisley, M.A. (*Cantab.*).
Roland Ralph Hole.
John Baker Hoyle.
Percy Desmond Francis Tweedie Huss, B.Sc. (*Manchester*).
David Graham Illingworth, Stud. Inst. C.E.
Robert Johnston.
Nathaniel Laird.
Robert William Langham.
George Herbert Lifton, Stud. Inst. C.E.
Hardwin Alexander Littlepage, B.Sc. (*Birmingham*).
Stephen James McNamara.
Alan Frank Mason, Stud. Inst. C.E.
William Matthews.
Digby Percy Cornwall Neave, M.A. (*Cantab.*).
Edward Ogden, B.Sc. (Eng.) (*Lond.*).
Frederick Russell Oliver.
Herbert Norman Pring, B.Sc. (*Manchester*), Stud. Inst. C.E.
Clarence Bertram Pyne.
Francis Stonier Rose.
Robert Miller Ross, B.Sc. (*Edin.*).
Pir Ghulam Jilani Shah.
James Shelly, M.C., B.E. (*National*), M.Sc. (*National*).
Gordon Soutar.
Henry Richard Tyrrell, B.Sc. (Eng.) (*Lond.*).
John Crossley Waddington.
Lawrence Edwin Wall.
William Douglas Walshe, B.Sc. (Eng.) (*Lond.*).
David Christie Watt, Stud. Inst. C.E.
Hubert Henry Westbrook, B.Sc. (Eng.) (*Lond.*).
John Edward Wheal.
Ernest Wilkinson, B.Sc. (Eng.) (*Lond.*).
Michael Laurence Wolfe-Barry, B.A. (*Cantab.*), Stud. Inst. C.E.
Alexander John Musgrave Young.

The following Paper was submitted for discussion, and, on the motion of the President, the thanks of The Institution were accorded to the Author.

Paper No. 5235.

"The Design of Sewage-Purification Works." †

By Herbert Cecil Whitehead, M. Inst. C.E.

TABLE OF CONTENTS.

Introduction.

The main purpose of this Paper, which is complementary to the earlier publications [1] by the Author in collaboration with the late Mr. F. R. O'Shaughnessy, is to discuss the general design of sewage-purification works in a manner helpful to engineers engaged in the design of such works, and to the managers entrusted with their operation.

The Design of Sewage-Purification Works.

A well-designed sewage-purification works should be an outstanding example of the civil engineer's skill in "directing the great sources of power in Nature for the use and convenience of man", for the Author knows of no other type of engineering work in which so many natural forces may be usefully employed.

The complications of design are due to the fact that it is necessary to attempt to direct a number of "sources of power" at the same time, and that some of these powers are apt to conflict with one another. Problems

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† Correspondence on this Paper can be accepted until the 15th July 1941, and will be published in the Institution Journal for October 1941.—Sec. Inst. C.E.

[1] "The Treatment of Sewage Sludge by Bacterial Digestion." Minutes of Proceedings Inst. C.E., vol. 233 (1931–2, Part 1), p. 38.

"Factors in the Design of Sewage-Disposal Works." "*Surveyor,*" Lond., vol. 88, p. 403; October 1935.

of few dimensions are comparatively simple, but in view of the number of unknown and partly-known factors which usually attend the design of sewage-purification works, it is no wonder that progress has been made empirically and that the fundamental scientific research which should form the basis of design has lagged painfully behind. An example is provided by the percolating filter or bacteria-bed, which has been in use for 50 years, and which may be regarded, with the sedimentation-tank, as one of the two most common devices used for the purification of sewage.

Past experience has provided knowledge of many of the factors necessary for efficiency in a percolating filter and of the various effects of these factors, but even now the reasons for such effects are not always known.

The method of sewage-purification should provide an orderly sequence of balanced operations designed to separate from the water, in successive stages, the different kinds of impurities contained therein, so that the appliances used are appropriate to the work required of them. This is obviously a commonsense arrangement similar to those adopted in agriculture and in the manufacture of composite materials.

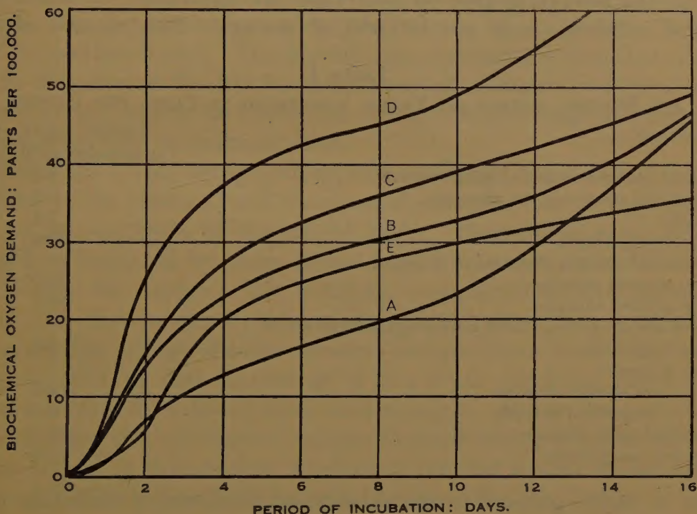
A double difficulty arises in sewage-purification, inasmuch as the necessary work has to be carried out without causing offence to the ratepayer's nose or pocket: but in actual fact, the urgent necessity of developing better methods of odour-control has resulted in lower operation costs. Obviously the first factor to be considered in designing a new sewage-purification works, or in extending an old one, is the sewage itself, and this necessitates the closest and most careful study of the composition, qualities, and behaviour of the sewage under known conditions before the method of treatment can be decided upon.

Although the total weight of polluting matter in sewage is usually only equal to 50–60 lb. of dry organic matter and 15–20 lb. of dry mineral matter per 100,000 lb. of water, its physical and biochemical conditions render separation tedious and difficult. A portion of the polluting matter exists in visible particles, part in true solution, and the remainder in the colloidal state. Because part of the polluting matter is of fæcal origin, sewage contains bacteria of the type which inhabit the intestines. The liquid which enters sewers from roads and land is also rich in a variety of bacterial life and in other small organisms and plants. The impurity in the sewage provides the food material upon which these organisms thrive, and the art of sewage-purification consists in exploiting this microbial activity so that the transformation of polluting matter to an inoffensive form is achieved.

The best results ensue when the engineer is able to design plant which affords the most suitable environment for the particular forms of bacteria he wishes to employ. Unless rendered inactive by the presence of sterilizing trade-wastes, such as gas-liquor, acid wastes, and similar substances, the bulk of the organic matter is usually readily fermentable, and is liable to cause nuisance unless its latent bacterial energy can be guided in the right direction. The strength of the sewage is determined not only

by the varying quantity of organic matter present, but also by its composition and condition. For example, fresh domestic sewage may be altered profoundly in condition by the addition of relatively small quantities of organic trade-wastes, some of which, such as wastes containing sugar, may hasten fermentation to such an extent as to render treatment both difficult and costly (*Fig. 1*).

Fig. 1.



Type of liquor.	Oxygen absorbed by N/80 permanganate in:	
	3 minutes.	4 hours.
A. Sedimented sewage.	1·25	9·70
B. " " + 1% gas liquor.	4·90	21·40
C. " " + 2% " "	7·68	32·00
D. " " + 0·05% sugar	1·20	40·90
E. 0·05% sugar inoculated with sewage effluent.	0·10	29·40

In order to obtain a true mental picture of the strength, composition, and condition of the sewage to be treated, it is necessary to examine a series of chemical analyses of carefully-averaged samples. The data given in Table I, p. 6, are typical of a domestic sewage when the daily dry-weather flow is approximately 30 gallons per head per day.

In Table I the figure for suspended solids does not represent the whole of the sludge-forming matter in the sewage, especially when the latter has been emulsified by pumping. A further determination of the quantity of colloidal matter present in a settled sample should be made, and this quantity should be added to the suspended solids figure. Moreover the solids which will aggregate during purification from matter in solution may amount to 20 per cent. of the total.

The values for free and saline ammonia, as nitrogen, and for albuminoid ammonia, as nitrogen, provide some measure of the strength of the sewage. They may vary inversely with the water-consumption, whilst the value for free ammonia may be increased by discharges of gas-liquor.

The alkalinity of a sewage expresses the quantity of alkali capable of being neutralized. For normal sewages the value is equivalent to about 30–40 parts of calcium carbonate per 100,000 parts by weight of sewage, that is, the sewage is able to neutralize the equivalent of about 30–40 parts of sulphuric acid per 100,000 of sewage. This reserve of alkali

Table I.

All Figures, except *p*H-Value, expressed in Parts per 100,000.

Appearance	Turbid, with brown suspended solid matter.
Free and saline ammonia, as nitrogen	4·5
Albuminoid ammonia, as nitrogen	0·8
*p*H-value	7·5
Alkalinity, as $CaCO_3$	32·0
Biochemical oxygen demand in 5 days:	
on shaken sample	35·0
on settled sample	20·0
Oxygen absorbed from n/80 permanganate at 80° F.:	
in 3 minutes	2·5
in 4 hours:	
on shaken sample	11·0
on settled sample	8·0
Suspended solid matter	28·0
Chlorides, as chlorine	10·0

serves a useful purpose in the subsequent biochemical oxidation of the nitrogenous substances present in sewage, because during this oxidation nitric acid is produced by bacterial means, and by neutralizing this acid as soon as it is formed the desirable action of oxidation is encouraged. The alkali reserve in sewage may also be useful in neutralizing acid trade-wastes discharged into the sewerage system.

The intensity of the acid or alkaline conditions existing in sewage is expressed by the *p*H-value, which is easily ascertainable. This must not be confused with total acidity or total alkalinity. The *p*H-value may be likened to the head of water available from a reservoir; the head is quite independent of the quantity of water passing through the reservoir. *p*H-values are expressed on a logarithmic scale, and range from zero to 14. Sewages with *p*H-values of 7 are neutral; those with higher values are alkaline, whilst those with lower values are acid.

The value for chlorine is not affected by purification unless an intentional increase is made by the use of sterilizing agents. It varies inversely with the water-consumption, and may be increased by infiltration into the sewers of sea-water, brine, or trade wastes containing chlorine.

The Author has purposely grouped the values for oxygen-absorption from n/80 potassium permanganate in acid solution in 3 minutes and 4 hours respectively at 80° F., and for the biochemical oxygen demand

(B.O.D.) of the settled sewage over a period of 5 days (*Fig. 1*), because he believes that they should always be considered together when used for unsettled and settled sewage samples.

The difference between the results for unsettled and for settled samples indicates the responsiveness of the sewage to sedimentation; but the tests upon the settled samples should receive particular attention. It is convenient to classify sewages roughly as "strong", "average", or "weak." In the Author's use of these terms the settled samples of these respective sewages have 4-hour oxygen-absorption values higher than 10, between 5 and 10, and less than 5. This classification corresponds with that adopted by the Ministry of Health for unsedimented sewages, and furnishes a measure of the task to be fulfilled in the biochemical stage of purification which follows that of sedimentation.

Whilst the 4-hour oxygen-absorption value and the 5-day B.O.D. are measures of the chemical and biochemical strengths respectively, they tell little of the condition of the settled liquor. Sewages of equal ultimate strength as indicated by these values may have widely different avidities or appetites for oxygen. For example, a small difference between the 4-hour and the 3-minute oxygen-absorption values may indicate the presence in the sewage of some chemical like gas-liquor with a high rate of oxygen-avidity, or that the sewage is in a septic condition owing to the presence of some stimulating agent such as sugar. In this case a study of a graph showing the biochemical oxygen demand during a period of 5 days will be helpful in determining whether or not the settled sewage will be easy or difficult to treat by biochemical means (*Fig. 1*).

One danger of depending solely upon the 5-day B.O.D. test is its liability to convey a wrong impression of the actual strength of the settled sewage. A very strong sewage containing considerable sterilizing trade-waste, and consequently having a high 4-hour oxygen-absorption value, may have a lower 5-day B.O.D. than that of domestic sewage of average strength. The objection to using the B.O.D. test alone does not apply to tests of purified effluents which are not in process of nitrification.

Steepness in the initial half of a 5-day B.O.D. curve indicates that the sewage is readily oxidizable, whilst a flat curve indicates the contrary. If either of these examples also yields a 4-hour oxygen-absorption value exceeding 10 parts per 100,000 on the settled sewage, it should be regarded as a "strong" sewage, although not necessarily difficult to treat, provided suitable means are used (*Fig. 1*).

The first example would probably be a sewage liable to cause nuisance from smell unless subjected to (*a*) activated-sludge treatment in aeration-tanks of relatively large cubic capacity, or (*b*) flocculation by activated sludge followed by treatment in percolating filters. The second example would probably be suitable for treatment in percolating filters alone, or, if the settled sewage contained considerable colloidal matter, by flocculation by activated sludge followed by treatment in percolating filters.

Some sewages, especially those containing trade-wastes, are much more amenable to sedimentation-tank treatment than are others, and for this reason analyses of the settled sewage should form the basis of calculations when the design of percolating filters or activated-sludge plants is under consideration.

Requirements for Inland Towns.

There are no legal standards of purification with which sewage effluents must comply, but the passing of solid or liquid sewage matter into streams is expressly forbidden by Part 2 of the Rivers Pollution Prevention Act, 1876. During recent years a general tendency has arisen towards acceptance of the standard recommended by the Royal Commission on Sewage-Disposal as a reasonable requirement for sewage effluents discharging into non-tidal streams. This suggestion of the Royal Commission, which was made in 1912, states that in order to be satisfactory an effluent should contain not more than 3·0 parts of suspended solids per 100,000, and with its suspended matter included should not take up more than 2·0 parts of dissolved oxygen per 100,000 in 5 days at 65° F.

Compliance with the letter of the Rivers Pollution Prevention Act, 1876, would be costly, if not impracticable, for most inland towns, but custom, with the approval of the Ministry of Health, ordains that schemes are generally acceptable which provide for complete treatment of sewage at rates ranging up to three times the average dry-weather flow, together with partial treatment for a further three times the average rate.

The Author considers that, whilst complete treatment up to three times the average dry-weather flow is sufficient, some extension of the second part should be made, in order to compel local authorities to apply partial treatment to a rate of flow higher than three times the average dry-weather flow.

The stages commonly in use at most inland sewage-purification works in this country are as follows :—

(1) Screening, for the removal of rags and other material of large size, both floating and heavier than water.

(2) Detritus- or grit-removal, for the separation from the sewage of sand and other heavy mineral matter.

(3) Sedimentation, for the removal of settleable solids, mainly of an organic nature, from sewage and storm-water.

(4) Percolating filters or activated-sludge plant, for the biochemical oxidation of dissolved and colloidal impurities.

(5) Humus tanks or separating tanks, for the removal of solids which have aggregated in the preceding stage.

(6) Sludge-treatment and disposal.

In some cases it may be advisable to interpose one or two additional stages between those already mentioned. For example, chemical treatment may be required between the second and third stages in order to

Fig. 2.

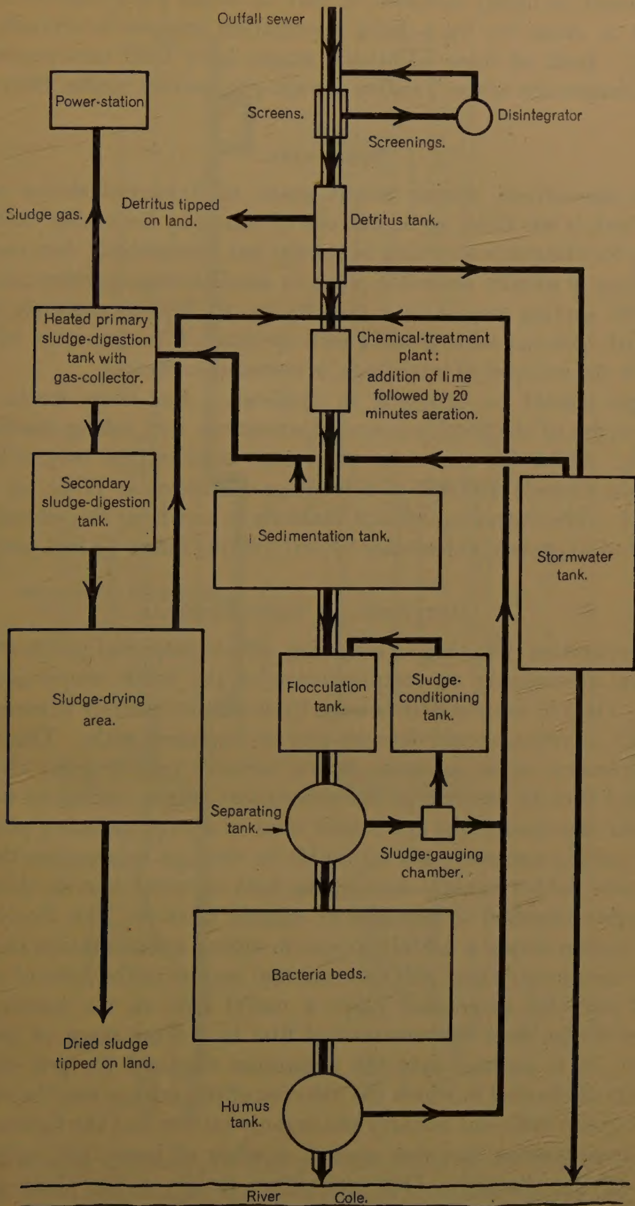


DIAGRAM SHOWING LAYOUT OF THE YARDLEY SEWAGE-PURIFICATION WORKS, BIRMINGHAM.

counteract the effect of certain trade-waste discharges; or, if the sewage to be treated be highly colloidal, it may be found advantageous to lessen the load in stage (4) by a brief flocculation process interposed within stage (3). Both of these additional stages have been incorporated in a recent enlargement of the Yardley sewage-purification works, Birmingham (*Fig. 2*).

Screening.

With the advent, during recent years, of improved sludge-pumping plant, which is less liable to be put out of action by becoming choked, the necessity for elaborate screening of sewage has diminished; but some form of screening is usually desirable, even in small sewage-purification works. For works serving populations ranging up to 20,000, a simple inclined screen with bars spaced to give 1½-inch openings, in conjunction with hand raking for the removal of screenings, is normally sufficient.

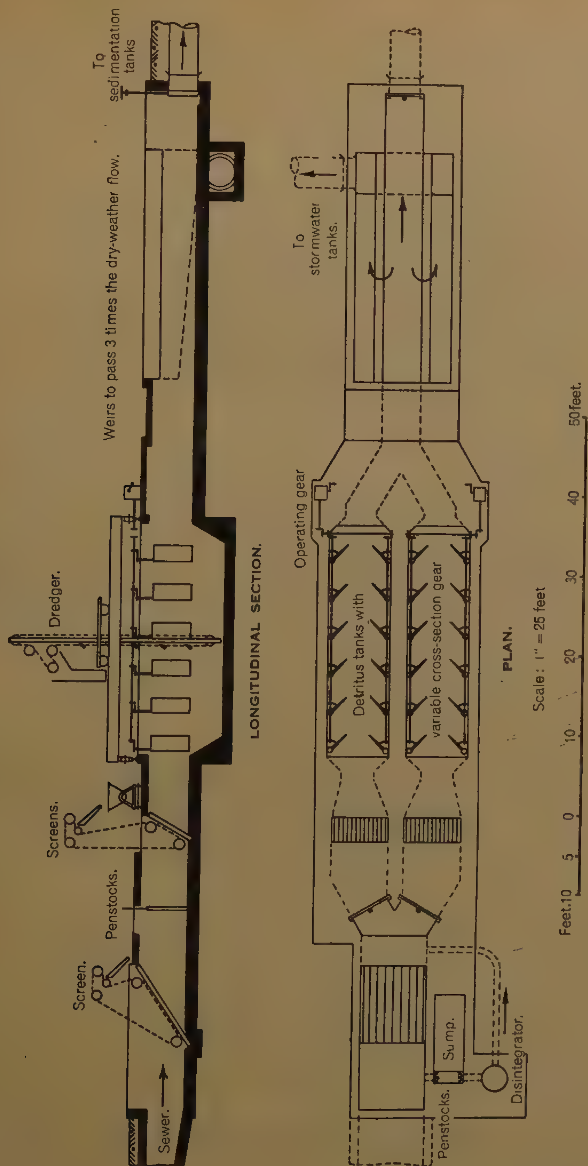
Screens should be arranged in duplicate. For large works several efficient types of electrically-operated screening- and raking-machines are available; whilst for the more important installations (say, where the population exceeds 100,000) a screenings-disintegrator (*Figs. 3*) may be employed. The entrance and exit channels to and from the screens should be designed to prevent the sewage-velocity falling below 1½ foot per second.

Detritus- or Grit-Removal.

This operation, like that of screening, effects little real purification, but is a usual preliminary to sedimentation of the solids suspended in the sewage. Only in dealing with sewage from an area entirely sewered on the "separate" system should detritus-pits be dispensed with. The object of detritus-removal is to separate heavy mineral matter from the lighter solids, and thus to prevent, in the subsequent stages, silting-up of sludge-mains and digestion-tanks and undue wear of sludge-pumping plant.

It is neither necessary nor advisable to attempt to separate the finely-divided and lighter mineral matter, the bulk of which travels through the detritus-pits attached to particles of organic matter. This finely-divided mineral matter serves a useful purpose in aiding sedimentation in the next stage of treatment, whilst still finer mineral matter in the form of clays in a state of colloidal suspension plays a useful part in the building-up of activated-sludge flocs or bacteria-bed film in a later stage of treatment. Therefore, it is evident that the apparatus required for grit-removal is some form of channel in which the velocity of the sewage may be controlled to give a speed sufficient to carry the organic matter and the lighter mineral matter in suspension, but slow enough to allow all heavy grit to fall to the bottom of the channel. This separation usually takes place when the velocity is about 1 foot per second. In order to ensure reasonable efficiency, control of velocity is necessary, as variations in rates of flow may range from one-quarter to six times the normal rate.

Figs. 3.



Screens and Detritus Tanks at Yardley, Birmingham.

In the smaller detritus-pits (for populations of up to 20,000) elaborate apparatus is not economical, and twin shallow channels ranging from 5 feet to 30 feet in length, from which the detritus can be removed by a hand shovel, are all that is necessary. In larger installations detritus is usually removed by mechanical means, as illustrated in *Figs. 3.* Washing of the

detritus so that the grit may be re-used is rarely profitable; but the efficiency of many existing pits of excessive capacity may be improved by

Fig. 4.

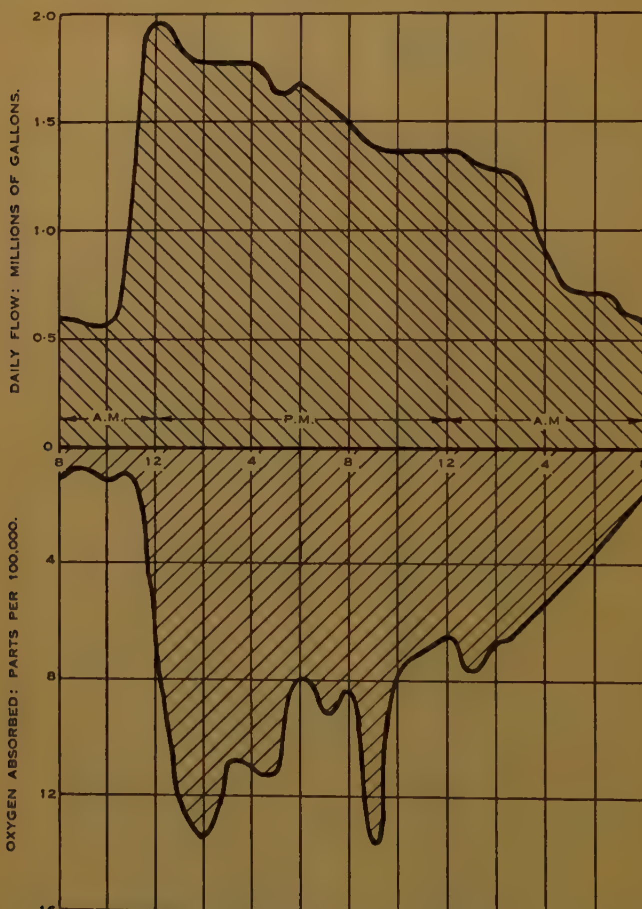


Diagram showing Daily Dry Weather Variations in Flow and Strength of Domestic Sewage.

disturbing the mixture of detritus and organic matter with compressed air immediately before its removal.

Sedimentation.

The functions of a well-designed sedimentation-tank system should be: (1) to effect separation of settleable solids; (2) to average the variations in the strength of the sewage; (3) to balance inequalities in the daily flow;

and (4) to provide time for self-purification, and thus to ensure that the minimum load is passed on to the subsequent oxidation-stage.

Restricted fall through the sewage-purification works may prevent the provision of balancing capacity; but the curves plotted in *Fig. 4*, illustrating the variations in flow and strength of domestic sewage over a period of

Figs. 5.

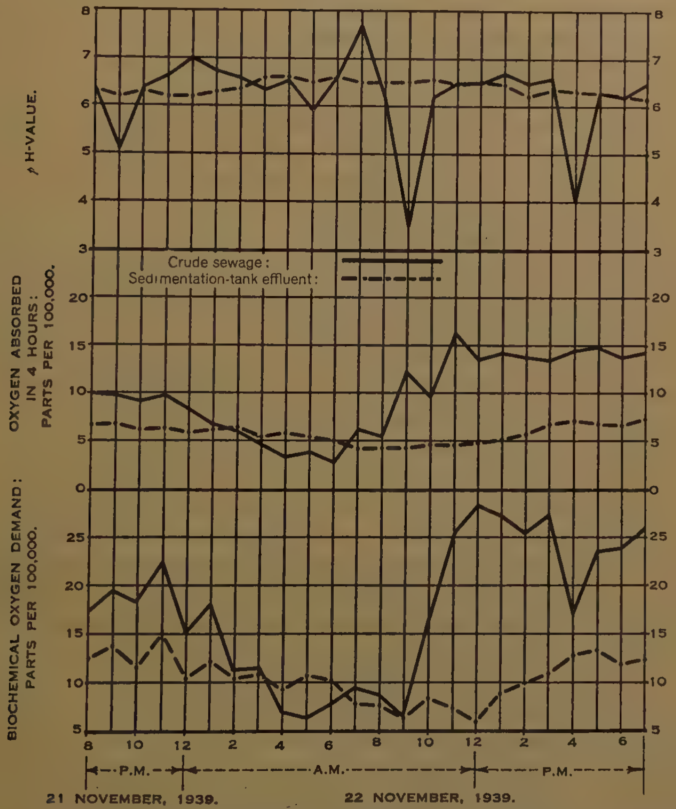


DIAGRAM SHOWING THE CHANGES IN STRENGTH OF SEWAGE AND TRADE WASTE AS A RESULT OF 9·2 HOURS' SEDIMENTATION.

24 hours, demonstrate the advisability of this neglected feature of sedimentation-tank design.

If the separation of settleable solids were the sole function of a sedimentation-tank, a capacity of one-sixth of the average dry-weather flow would normally suffice for flows ranging up to three times the dry-weather flow; but most average-strength and strong sewages need a much longer period than this for full advantage to be taken of their power of self-purification, and of the averaging of strength which occurs when the detention-period is lengthened beyond that required for separation of the suspended solids (*Figs. 5*).

With strong sewages containing considerable trade-waste of an antiseptic or neutral character (low B.O.D. and flat curve) it will usually be found profitable to provide generous tank-capacity (12–18 hours). When the sewage is weak and readily oxidizable, tank-capacities of 6–8 hours are usually sufficient. With strong sewages containing much fermentable matter (high B.O.D. and steep curve), a long detention-period would be liable to cause smell nuisance, unless this were checked by dividing sedimentation into two stages and interposing in the gap between them a brief period of flocculation with activated sludge.

When a large sedimentation-capacity is desirable, rectangular tanks are usually the most economical form of construction. On the other hand, economy in labour and general efficiency are best provided by tanks which are mechanically cleaned, and a circular radial-flow tank represents the best form of construction for this purpose. In large installations (population 100,000) it may often be found advantageous to combine these two forms of construction by dividing sedimentation into two stages, in which the relative capacities of the two stages are as 1 to 2. The first stage then comprises radial-flow tanks with sludge-removal by mechanical scrapers, whilst the second consists of rectangular tanks cleaned manually. In this combination about 75 per cent. of the settleable sludge-forming matter is arrested in the first stage, leaving only one-third of this quantity to be dealt with in the larger tanks comprising the second stage. Most of the secondary sludge, being light and finely-divided, flows readily to the sludge-outlet, and little labour is required to remove the remainder by squeegee. Although the relative proportions of sludge-forming matter in the two stages are as 3 to 1, the higher water-content of the sludge in the second stage usually equalizes their bulk proportions. Incidentally, rectangular tanks lend themselves to adaptation for balancing the flow more readily than do circular tanks.

Considerable scope still exists for research in connexion with the design of various forms of sedimentation-tanks. The problem is complicated by the varying nature of the fourfold requirements mentioned earlier, and by the bacterial and chemical forces at work in the sewage. For example, the longer period required for the self-purification of the liquor also allows contrary bacterial forces more time to react, and when the flow through the tanks is very uneven, smell nuisance and an ill-conditioned tank-effluent may result.

In a badly-designed hopper-bottom tank from which the sludge is discharged by hydrostatic head, it is possible, because of short-circuiting and stream-lining, for the period of detention in certain portions of the tank to vary from 4 hours to 4 weeks—and this in a tank having an average detention-period of 12 hours!

The principal aims in the design of sedimentation-tanks should be simplicity, the avoidance of unnecessary surfaces for the adhesion of sludge or scum, uniformity of flow from inlet to outlet (excepting that portion of

the tank retaining sludge), the avoidance of unnecessary perturbation at the tank-inlet by even diffusion of the kinetic energy in the incoming sewage, and ample provision for easy and efficient removal of sludge and scum. When sufficient head is available, and horizontal-flow tanks are contemplated, they should be designed to balance, so far as possible, the inequalities of the dry-weather flow (*Fig. 6*).

Circular and square tanks with bottoms shaped like inverted cones or pyramids and sludged by hydrostatic head only are much more suitable for use as humus-tanks (wherein the period of detention is short and the sludge is light) than for the sedimentation of crude sewage. In tanks of this type

Fig. 6.

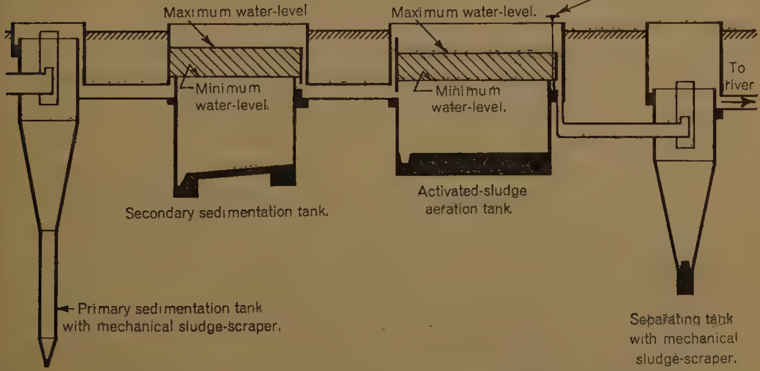


Diagram showing Flow-Balancing Arrangement at Coleshill, Birmingham.

it is difficult to effect complete removal of the crude sludge without the use of an unduly large proportion of water, whilst it is also difficult to check anaerobic action in the sludge clinging to the slopes of the tanks.

The function of storm-water sedimentation-tanks is usually assumed to be that of providing partial treatment (sedimentation) for rates of flow exceeding three times the average daily dry-weather rate. When properly designed and operated, they may do much more than this, because if adequate pumping equipment be provided for emptying purposes, the tanks may be used so as to enable a large portion of the flow in excess of three times the dry-weather rate to receive complete treatment. For this purpose the sewage-works manager should not allow a storm-water tank to remain filled, or partly filled, at the end of a storm for a longer period than is reasonably practicable. The first flush of storm-water is usually much more foul than dry-weather sewage, and if the storm is of brief duration and storm-water tanks of sufficient capacity are standing empty, no overflow of partially-purified liquid occurs, and the whole of the liquid contents of the tanks may be passed forward for complete treatment during the subsequent 24 hours.

Other reasons for not allowing storm-water tanks to remain full longer than is necessary are that septic action may set in and cause smell nuisance, or a second storm may cause displacement of the foul contents of the tanks into the river.

There are, of course, very considerable yearly variations in the quantities of sludge arrested in storm-water tanks. Observations at Birmingham indicate that the storm-water sludge-recovery may amount to 25 per cent. of the total arrested in the sedimentation-tanks, whilst in an exceptional year the quantity recovered from the storm-water tanks was only 5 per cent.

On account of the large capacity and the comparative infrequency of use of storm-water tanks, it is usually not economical to equip them with mechanical sludge-scrapers. The commonest forms are rectangular horizontal-flow tanks, with floors sloping to central sludge-channels, as illustrated in *Figs.* 7.

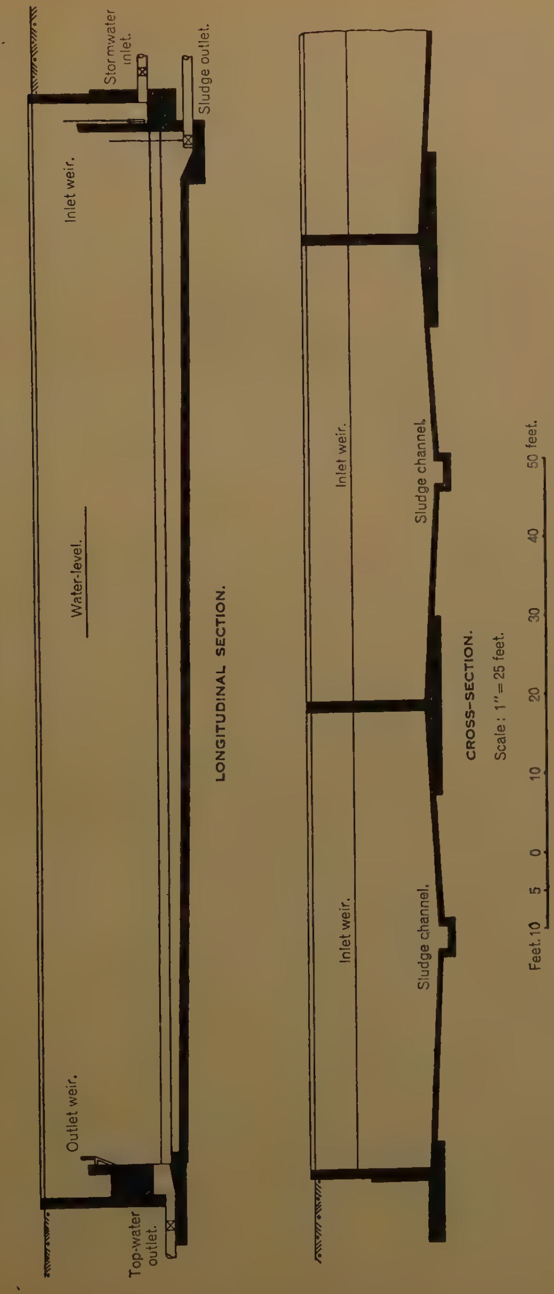
The required capacity of storm-water tanks varies within wide limits, and is dependent upon the rate of run-off in the drainage-districts, the sewerage system in use (separate, partially-separate, or combined), and the character of industrial development. In the case of a district separately sewered (that is, with two distinct sewerage systems, one for sewage and one for surface-water drainage), no storm-water tanks are necessary if the maximum rate of discharge does not exceed three times the average rate. For partially-separate sewerage systems, and for combined sewerage systems in a flat district with a low rate of run-off, a storm-water tank-capacity of 6 hours (one-quarter dry-weather flow) will usually be sufficient. Generally, in industrial towns, capacities of 9–12 hours are necessary, because sewages are stronger, a higher proportion of the drainage-area is paved, and the run-off is more rapid. Instances even occur of large industrial towns at the head of small streams where a storm-water tank-capacity of 18 hours should be provided.

Percolating Filters.

The outstanding suitability of the bacteria-bed or percolating filter as a device for the purification of dissolved impurities was indicated by Mr. F. Wallis Stoddart[1], of Bristol, in 1911, but even now this fact is not sufficiently well known, and instances frequently occur wherein the efficiency of well-constructed filters is seriously impaired by the distribution over their surfaces of imperfectly-treated liquor containing too much sludge-forming matter in a state of suspension, either as colloidal matter or visible particles. The flocculation and deposit of this excessive quantity of sludge-forming matter in the upper 12–18 inches of the filter, in conjunction with the fungal growths thus fostered, effects a mechanical check upon the quantity of liquid that can percolate through the overworked surface-

[1] "Nitrification and the Absorption Theory. An Account of the Principles of the Modern Sewage Filter." Printed for private circulation, 1911.

Figs. 7.



STORM-WATER TANKS AT COLESHILL, BIRMINGHAM.

layer to the underworked lower portion. Once surface chokeage sets in, other ill-effects, such as defective aeration and unequal distribution, help in further reducing efficiency.

The oxidizing-capacity per unit volume of percolating filters when dealing with dissolved organic impurity, or with sewage relatively free from suspended and colloidal matter, is evident from the following examples :—

(1) A laboratory filter, containing $\frac{1}{8}$–$\frac{1}{4}$-inch medium, treated a mixture of sugar, lactic acid, and ammonia in solution at the rate of 100 gallons per 24 hours per cubic yard of medium. The B.O.D. of the liquor applied was 63·9 parts per 100,000. The effluent had a B.O.D. of 1·2 parts and was nitrified [1]. In this case, the load was equivalent to a rate of about 300 gallons per cubic yard of settled domestic sewage, whereas the usual treatment rate is 100 gallons per cubic yard per 24 hours. A permissible inference from the experiment is that whilst the "liquor-facility of treatment" of a percolating filter, when treating liquid containing only dissolved impurities, may be taken as 100 per cent., the facility decreases to 33 per cent. when an equal load is applied in a mixture of suspended and dissolved impurity.

(2) A sewage which received partial treatment in an activated-sludge plant at Minworth (Birmingham) was treated under adverse winter conditions during January 1939, at the rate of 128 gallons per cubic yard per 24 hours. The 4-hour oxygen-absorption value of the treated sewage was 5·6 parts per 100,000, whilst the effluent had a value of 1·2 part per 100,000. Before partial treatment by activated sludge the liquor had a strength only 44 per cent. higher, but owing to the quantity of colloidal and other suspended matter present, its permissible rate of application to a percolating filter was only 60 gallons per cubic yard per 24 hours.

The examples cited illustrate only one of the factors affecting the purification-capacity of a percolating filter. Other factors which must be considered in attempting to estimate the overall capacity are the distribution, the nature of the medium, the temperature, and the ventilation for aeration purposes. Very high efficiencies in some of these factors (which are discussed later) are not practicable at reasonable cost, whereas others are comparatively easy of attainment ; but all require careful consideration if the design of an appliance appropriate to its task is to be achieved.

The work of purification will be carried out by bacteria and other organisms, which will eventually find a home on the surface of the medium with which the filter is to be filled. The problem is akin to that of establishing an industrial community of selected workers, feeding them, and arranging their living and working conditions so as to encourage the greatest output of useful work. To do this successfully requires the housing (without overcrowding) of the maximum number of useful organisms, the even

[1] "The Purification of Waste Waters from Beet Sugar Factories." Water Pollution Research Technical Paper No. 3. H.M. Stationery Office (1933).

provision of food and oxygen, and a suitable temperature, together with a water-supply and drainage system. The water-supply may be likened to a means of transport for the distribution of food, oxygen, and work, and the drainage system to the discharge of the finished work (purified water) and the debris of microbial activity (commonly known as humus).

The greatest progress in any of the five factors affecting percolating-filter capability has been attained in mechanical distribution. Several types of sewage-distributors, suitable for both circular and rectangular filters, are available, which may be said to have an efficiency of 90–95 per cent. when supplied with liquid at a constant rate, for they are capable of applying the liquid evenly to 90–95 per cent. of the area of the filter.

With all types of mechanical distributors intermittent distribution is usual. Experiments carried out at Birmingham on percolating filters with coarse medium (1½–2½ inches) revealed no perceptible disadvantage in this intermittency until the dosing-intervals exceeded 10 minutes. With finer medium the permissible intervals would, of course, be longer. Distribution by means of fixed spray-jets may be moderately efficient at high rates of application, such as those adopted in some American plants, but with a rate of application of 240 gallons per square yard per 24 hours, it is rarely possible to cover evenly more than 60 per cent. of the filter-area.

The selection of a suitable percolating-filter medium is often difficult, and only by a careful assessment of the qualities which rival materials offer in relation to cost can a choice be safely made. The requisites of a good medium comprise : (1) durability ; (2) a proportion of voids to total volume of at least 45 per cent. ; (3) a relatively large ratio of surface to volume ; (4) a rough surface such as will assist the adhesion of bacterial film ; and (5) low heat-conductivity.

The materials usually available include clinker, coal, coke, slag, saggars, granite, quartzite, flints, and other hard stones of good weathering quality. Although clinker would satisfy four of the five requirements mentioned above, its durability is often questionable, and even the most carefully selected clinker is rarely serviceable for longer than 25 years. Some gas-coke filters are still giving good service after 35 years' operation ; but many gas-cokes are not durable. Probably the best material available in this country is metallurgical coke ; but, as its production is limited to two or three localities, the cost of transport has restricted its more general use. Slag, saggars, granite, and broken quartzite are suitable materials, having about equal value as filtering-media. Slag should contain not more than 1 per cent. of iron oxide and not more than 2 per cent. of calcium sulphide, and should be well washed after being crushed. Flints, unbroken quartzite, and other gravels, although of high durability, do not comply fully with the other requisites, and usually filters filled with these materials should have a cubic capacity 25 per cent. higher than that of filters filled with broken material.

Considerable diversity of opinion exists in regard to appropriate sizes

and grading of media. Thirty-five years ago filters usually consisted of a 12-inch upper layer of fine medium (¼–½ inch), and a 12-inch lower layer of coarse medium (3–6 inches), with a middle layer of some intermediate size. The principal object of the layer of fine medium was to counteract inequalities of distribution, whilst that of the coarse layer was to provide drainage. With better distribution and the provision of properly-constructed aeration-floors, the need for variation in the size of medium no longer exists, and, apart from a few inches of coarse material to cover aeration-tiles, the medium should be uniform in size over its whole depth. The size selected should depend upon the character of the liquid to be treated. Small-size medium (½–1 inch) may be used safely with liquids which have been freed of suspended and colloidal matter, but filters designed to effect partial treatment at high rates of flow require a coarse medium (3–4 inches) in order that the large voids may facilitate the evacuation of flocculated matter which must, of necessity, be forced through with the partially-purified effluent. The most useful size of medium for well-sedimented sewages which have not been subjected to a flocculation-treatment is 1–2 inches.

As the period of retention of the liquid in the filter decreases with increase in the size of the medium, it is desirable, for the sake of purification efficiency, that the medium should be only large enough to ensure that the filter is self-cleansing.

Bacterial action is most efficient when the interior temperature of the filter is between 80° and 90° F. It is perhaps due to the comparative mildness of English winters, and to the warmth of the sewage itself, that greater regard is not paid to the effect of temperature upon aerobic action in filters and activated-sludge plants. Many English industrial sewages have winter temperatures exceeding 50° F., and there are even instances of temperatures of 80° F. ruling for the greater part of the year. Under these conditions, although a perceptible reduction in efficiency occurs during, say, 4 months of the year, the filter acts as a storage reservoir for impurity which is collected during the winter and is discharged as humus during the summer period of intensified bacterial and insect activity. This characteristic has deservedly earned the percolating filter a good name for reliability under varying conditions of load and temperature.

From time to time attempts have been made to improve the efficiency of filters by alterations in methods of construction and operation.

The benefit to be derived from protecting the filter against heat-losses is likely to be greater in countries where wide variations exist between winter and summer temperatures and where the filters are intended to effect partial treatment at a high rate of flow, than in England, where temperature-variations are moderate and it is usual for effluents to be purified to a high standard. The efficiency of ventilation depends not only upon constructional details, but also upon the medium, the method of distribution, and, above all, the condition of the surface of the filter. The best results are

obtained when (*a*) the whole of the filter-floor is covered by aeration-tiles with air-outlets on at least two sides of a rectangular filter, or spaced evenly around the circumference of a circular filter; (*b*) the voids in the medium correspond to about 45 per cent. of the mass; (*c*) the distribution of the sewage over the surface is even; and (*d*) the surface-layer of the filter is clean.

Some trade-waste liquors, such as milk wastes, contain so much matter in a state of colloidal suspension that their treatment by ordinary methods of single filtration is difficult. It was established by the Water Pollution Research Board, in an important investigation carried out at Ellesmere between 1935 and 1938, that milk and other dairy wastes may be satisfactorily purified by a method of double filtration, in which the order of the filters is changed at intervals of 2–3 weeks. Details of the investigation were published in the annual Reports of the Water Pollution Research Board for the years 1936 to 1938. These indicate that milk-waste liquors are most suitable for treatment when diluted with effluent so that the mixture has a 5-day B.O.D. of 20–25 parts per 100,000. At this strength it may be purified to a B.O.D. of 1 part per 100,000 at the rate of 160 gallons per cubic yard of medium per 24 hours, as calculated on the total contents of the two filters. As this rate is about 50 per cent. higher than the rate at which it is possible to purify, by single filtration, sewage of equal strength, an investigation is being conducted by the Water Pollution Research Board, in co-operation with the Birmingham Tame and Rea District Drainage Board, at Minworth (Birmingham), with the object of comparing double filtration and periodical changes in the order of the filters with single filtration as a means of purifying sedimented sewage. There is reason to expect that this method of alternate filtration will be even more effective with sewage than with milk-waste.

On p. 16, *ante*, it was mentioned that flocculation and deposit of sludge-forming matter in the upper 12–18 inches of a filter-bed caused a mechanical check on the quantity of liquid which would otherwise be able to percolate to the underworked lower portion. Both the method of alternate filtration just described, and the Birmingham method of bio-flocculation by means of activated sludge as a preliminary to filtration, are means of overcoming this disadvantage. Each of these methods functions in an orderly manner by providing for the regular discharge of flocculated deposit; but it is not yet practicable to make a detailed comparison of the respective merits of the two processes.

Another variation from the ordinary method of utilizing the percolating filter is the enclosed aerated filter. In this method, which is a re-application of an old idea, the filter is completely enclosed and subjected to a gentle forced aeration, the innovation being that aeration is downwards, instead of upwards, as in earlier experiments. The results already obtained from investigations in progress at Wolverhampton and Johannesburg afford evidence that the enclosed filter presents advantages, especially in cases

wherein it is desired to effect partial treatment at high rates of flow. It is unfortunate that the enclosed filter was heralded with extravagant claims before its value could be authoritatively assessed, but this is by no means an uncommon experience with new processes and methods.

Activated-Sludge Treatment.

Activated sludge is produced by the aeration of successive portions of sedimented sewage, which results in the formation of a living mass of organisms. If the sludge is kept supplied with sufficient oxygen and is brought into contact with sewage, it effects purification by flocculating and absorbing suspended and colloidal solids, whilst dissolved impurities are immediately rendered available as food material for the organisms. These processes take place simultaneously, although flocculation and absorption of suspended and colloidal solids occur rapidly and are completed first. In order to attain its maximum efficiency, the sludge has to be aerated for a period long enough to oxidize part of the organic matter removed from the sewage; otherwise it becomes overloaded with impurities and ceases to function satisfactorily.

In the activated-sludge process, liquid activated sludge is maintained in contact with sedimented sewage in the presence of ample atmospheric oxygen for a period sufficiently long to enable it to accumulate and assimilate a proportion of the dissolved and colloidal sewage solids. The activated sludge is then separated in sedimentation-tanks from the purified sewage, part being available for re-use, and the surplus being discharged for treatment and disposal either separately or mixed with crude sewage-sludge.

The activated-sludge process (and in this description the Author includes all methods of operation) possesses many advantages in comparison with percolating filters, and labours under only one disability, due to the low rate at which a mass of sewage can take up atmospheric oxygen. This disability, however, may be largely counteracted in design. In a percolating filter the mass of sewage may be spread out in a thin film over the surface of the medium, thus presenting an aeration-surface infinitely greater than that produced by the most efficient form of aeration device yet employed in any activated-sludge plant. This is why certain sewages, not necessarily very strong, but with a high initial avidity for oxygen, may be difficult to treat by the activated-sludge process unless special means are employed in the design and operation of the aeration-plant to ensure that the initial high rate of oxygen-demand is adequately met.

The most convenient means of doing this is to employ a much greater quantity of oxygenated water than is usual for the circulation of activated sludge. A normal sludge-return for circulation through the aeration tanks is 33 per cent. of the sewage-flow. For sewages having a high initial avidity for oxygen this proportion should be doubled for normal use, and trebled on occasions of exceptionally high demand. The principal object

of increased circulation is to effect a better balance between the demand and the supply of oxygen. It does not alter the actual period during which the sewage undergoes aeration, and the ill-effect of any short-circuiting of partially-purified liquid is more than counterbalanced by the increased efficiency of the activated sludge.

Another way of ensuring a good balance between the supply and the demand of oxygen at the commencement of activated-sludge treatment is to avoid coupling aeration-channels or tanks in series. When sedimented sewage enters four short aeration-channels, working in parallel, it receives an initial dilution with oxygenated water four times greater than when the same channels are worked in series.

Failures and inferior performances by some of the earlier activated-sludge plants were often caused by unnecessary overloading. The activated-sludge plant, like the percolating filter, should not be employed for work which would be better carried out in the previous stage of sedimentation. Until the creation of surplus activated sludge can be economically justified by its value as a fertilizer, the aim in design and operation should be to arrange matters so that the quantity of surplus activated sludge is the minimum consistent with efficient purification. The building-up of activated sludge from dissolved sludge-forming matter, and matter in colloidal suspension in sedimented sewage, is a costly operation, and not only is the creation of unnecessary surplus sludge a waste of power, but also, owing to its considerably increased bulk, in comparison with crude sludge, its subsequent treatment and disposal is not economical.

In the activated-sludge process, as in other processes which are largely biochemical, temperature plays an important part. The most favourable temperature is about 90° F., but the process functions well at winter temperatures of sewage, which in England are usually above 50° F. The diffused-air method of aeration tends to conserve heat in the aeration-tank, as the air is warmed during compression, whereas methods of surface aeration tend to cool the liquid. The loss of heat in winter by these latter methods is, however, slight; the observed average difference at Birmingham was only 3·4° F. during the coldest 3 months of 1933. The required periods of detention in aeration-tanks differ with the variations in strength and avidity for oxygen of the sedimented sewage, the method of aeration employed, and the design of the aeration-tank. With the same sewage, detention-periods using different means of aeration may vary from 8 hours to 24 hours; but usually there is little difference in the energy-consumption per million gallons treated, whichever of the four or five established methods of aeration is employed.

The activated-sludge process may be used to carry purification to stability, or to effect a partial treatment for the removal of colloidal matter from sedimented sewage, such as occurs in the bio-flocculation process in operation at Birmingham and other places. For the bio-flocculation process, it is necessary to maintain the sludge in a condition of activity in a

separate conditioning-tank. Such a tank may also be advisable in a complete treatment plant, which is subjected to intermittent trade-waste discharges of toxic character.

In the purification of many strong sewages, a combination of the bio-flocculation process and the percolating filter forms a cheaper and more efficient method than the use of activated sludge or percolating filters as single processes. The reason for this superiority is that in the combined process each part is utilized to perform the work for which it is most suitable; that is, activated sludge for the flocculation of colloidal matter, and the percolating filter for the oxidation of dissolved impurities. The combined process has the further advantage of affording greater protection against smell and fly-nuisance than the percolating filter working alone is able to give. On the other hand, activated sludge as a single process requires a lower fall and a smaller area than are needed for percolating filters or the combined process. The aim of bio-flocculation is to improve the "liquor-facility of treatment" preparatory to its application to the filter; and as the Author has shown in the case of sedimented domestic sewage, this may be as low as one-third of that of a liquor of equal strength but composed entirely of dissolved impurities. A bio-flocculation treatment of 1 hour's duration is usually sufficient to double the "liquor-facility of treatment" of a strong or average sewage.

Tanks for the Separation of Humus and Activated Sludge.

These tanks, unlike sedimentation-tanks for sewage, are required for one purpose only, namely, the separation of settleable solids. Upward-flow tanks should be designed to limit the upward rate of flow to a rate lower than that of the settlement of solids carried in the liquid, which may range from 6 feet per hour, for some activated sludges, to 10 feet per hour for humus from a percolating filter. In order to ensure the circulation of fresh activated sludge or humus, upward-flow tanks should be equipped with some simple form of scraper mechanism. Horizontal-flow humus-tanks usually require a capacity of one-quarter the daily dry-weather flow if rates of up to three times the dry-weather flow have to be dealt with.

Sludge-Treatment and Disposal.

For many years sludge-treatment and disposal has been the most neglected portion of sewage-works design. Too often the only method suggested by the engineer was to pipe the sludge to the lowest portion of the sewage-works site, in the hope that the sewage-works manager would be able to perform some unspecified miracle. Naturally, the usual results were obnoxious smells and the pollution of nearby water-courses.

For small communities with sewage works in rural surroundings, sludge-treatment may not be necessary, provided that the sludge-drying area is ample and well-drained, with provision for returning the drainage-water for

treatment. In areas where protection against smell nuisance is desirable, the treatment of sludge by bacterial digestion, followed by drying on open underdrained areas, still affords the best protection, and is usually more economical than any other method of sludge-treatment.

Since the Author and Mr. O'Shaughnessy presented their joint Paper in 1931 [1], there has been little progress to record in sludge-treatment, other than the more general adoption of bacterial digestion. Incineration of sewage sludge, after dewatering in vacuum filters, as a feasible method of disposal, has made progress in some American towns—particularly Chicago—but in England there is little prospect of its adoption, except in rare cases where site restrictions or other factors, such as pollution of underground water, prevent the provision of digestion-tanks and sludge-drying areas. The disposal of digested sludge from small and moderately-sized works is rarely difficult when the dried sludge is in a suitable condition for transport and application to the land, and the radius of delivery to adjoining farms does not exceed 2–3 miles. Under these conditions farmers will usually take all of the available material, and will, in some cases, make a small payment; but provision must be made on the sewage-works site for the storage of sludge during the greater portion of the year. Good loading facilities are necessary to enable the year's output of sludge to be removed during short periods, often totalling only 6 or 8 weeks.

The disposal of sludge from large works (100,000 population and upwards) becomes more and more difficult as the radius of distribution increases. In these cases better means of conditioning the dried sludge, such as storage under cover and grinding the lumps to a fine meal, increase the quantity sent back to the land; but progress is slow, and on most large works provision for tipping many years' surplus will continue to be necessary.

In conclusion, the Author would emphasize the necessity for attention to the general arrangement and appearance of all sewage-purification works. A moderate expenditure on paths, the planting of trees and shrubs, and the provision of clean accommodation for the men will do much to ensure working efficiency.

Acknowledgements.

The Author desires to express his thanks to Dr. H. T. Calvert, M.B.E., Director of Research, Water Pollution Research Board, and to Mr. L. F. Mountfort, Assoc. M. Inst. C.E., for their helpful criticism of his Paper when in draft form, and also to Dr. S. H. Jenkins for the chemical analyses and oxygen-demand curves prepared to illustrate portions of the Paper.

The Paper is accompanied by seven diagrams, from which the Figures in the text have been prepared, and by two photographs.

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[1] *loc. cit.*

Discussion.

The Author, in introducing his Paper, showed a number of lantern slides.

He observed that one criticism which had been made of the Paper was that he had devoted twice as much space to the percolating filter as to the activated-sludge process. The only reply he could give was that he had known the percolating filter for 40 years, and the activated-sludge process for only half that time.

Mr. R. G. Hetherington observed that the Author had referred to progress in the design of sewage-purification works having been made empirically, especially in connexion with the percolating filter. That recalled to mind the fact that the late Mr. Santo Crimp, who he believed put up the first contact-bed, told him when he was a pupil the origin of that contact-bed. He had had a filter which was intended purely as a straining filter, but he could not induce the sewage to flow evenly over it; he therefore put a valve on the outlet and filled the filter, so that every part of the filter-material had to do some straining; and from that came the contact-bed.

Mr. Hetherington supported the Author in emphasizing the necessity of finding out what it was that one had to deal with before starting to deal with it. Many people were inclined to think that all sewage was the same. Therefore works were sometimes designed which were not the best for dealing with a particular sewage, although they might be excellent for dealing with another type of sewage somewhere else. It had been suggested by some that among the factors which might affect the consideration of sewage-treatment was the nature of the water-supply in the area—whether it was a hard or a soft water. He did not think that that point had been satisfactorily settled, and he would be glad to have the Author's views upon it.

Throughout the Paper, and in many other discussions on sewage purification, reference had been made to three-times dry-weather flow and six-times dry-weather flow, as if those figures were fixed as the limits of the purification which should take place. That was quite true with regard to three-times dry-weather flow, but he did not think that it was true with regard to six-times dry-weather flow. He thought that, if the Report of the Royal Commission on Sewage-Disposal were read carefully, it would be found to bear him out in saying that the six-times limit came entirely from the sewer end, and not from the sewage-disposal end, that was to say, the six-times rate was fixed as a reasonable figure at which overflow discharge from the sewer might be allowed, and that allowance was made for

the purpose of preventing the sewers becoming too large and expensive, as would be the case if, say, twenty times the dry-weather flow had to be carried, which might happen even in a partially separate system. His department would object to the installation of a six-times dry-weather overflow at the entrance to the works in order to cut down the amount to be treated as storm-water. If something more than six times had been taken down to the works, as was generally the case (it was more likely to be ten times), then the balance over three times should be treated as storm-water.

The Author had referred to disintegration as a part of screening, but he had not touched upon one rather important point—disintegration as applied to sea-outfalls. The Ministry of Health took the view that, in such cases, disintegration should not be substituted for screening, if screening were feasible, because one process removed the screenings entirely, whilst the other merely chopped them up and sent them out; but at some places screening was not feasible, and disintegration had a beneficial effect in such a case. The most marked case he knew of was at a town on the south coast of England, where formerly sea gulls had congregated around the sea outfall, but after a disintegrator had been installed not a single gull appeared.

The Author had referred to detritus-tanks and grit-removal, and had rather suggested that they were not necessary in an entirely separate system; but he would like to ask whether the Author knew of any system which was so entirely separate that it could afford to do without a detritus-tank. He was not referring to the sewage works of an institution, where one had complete control, but to the case of public systems. In the one with the most rigid separation that he knew of, the flow rose to two-and-a-half times in rain. There were so many back-yards and grit-delivering areas that it was doubtful whether any public system could afford to dispense with detritus-tanks.

He thought that there was still a great deal of scope for research into the design of tanks. He did not think that sufficient was known about their operation and the most efficient form having regard to the type of sewage with which they had to deal.

During recent years one or two installations on a very large scale had introduced a rather new factor which should be borne in mind. They covered such a wide area that the standard storm-water tank had, in effect, become much larger, in proportion to the flow arriving at the works at any one time, than in the smaller works. This was due to the fact that storms might occur on only part of the area, and a heavy rainfall might by no means cover the whole area. The flows coming down were delayed, and it seemed to him that there was a balancing of the flow which made the storm-water tank of the normal size more in proportion than it was in the smaller works. Possibility of trouble also arose because the sewage might become septic owing to the length of travel before reaching the works. Those were

two problems which had occurred to him in connexion with large works, and he thought that they needed consideration.

Dr. H. T. Calvert observed that he had had the pleasure of participating in the Discussion on the earlier Paper [1] presented by the Author and the late Mr. O'Shaughnessy. He considered that the two Papers could definitely be regarded as a *multum in parvo* edition of the Fifth Report of the Royal Commission on Sewage-Disposal, brought up to date. The Author had had exceptional opportunities of continuing the work of that Commission, and had used those opportunities to the full. The secret of the success of the work of the Author and of the Royal Commission lay in the fact that their conclusions had been based upon experimental research in which the numerous factors concerned had been varied one at a time for the purpose of examining the effects produced. That opened up a very wide field of research, which naturally formed part of the program of the Water Pollution Research Board, of which the Author had been a member since it was set up in 1927.

From what he had said it might be gathered that the Paper was a textbook on sewage treatment. If one glanced at the textbooks which had been published on the subject during last century, it would be found that in the latter half of that period most of them were descriptions of sewage-purification works carried out by their authors, and contained little discussion on the principles underlying the design of those works. It was with the advent of Professor Dunbar's textbook [2] on the principles of sewage treatment that that aspect of the subject had been opened up; and the translation of that book, which Dr. Calvert had undertaken in the early years of the present century, had inspired his education on the subject of sewage treatment. Probably no aspect of the civil engineer's art of "directing the great sources of power in nature for the use and convenience of man" had given rise to more controversy than had the theories underlying the design of sewage-purification works, and finality had not yet been reached.

The Author had begun by assessing the polluting character of a sewage by the weight of polluting matter it contained. It was natural for a mechanically-minded man to think first of all in terms of weight, but the nature and the character of the polluting matter must not be lost sight of, and were definitely of great importance. Those interested in the subject were still groping for an accurate measure of the polluting character of the matters contained in sewage. As the Author had stated, it was only by applying several tests that a proper assessment of polluting character could be made. Each new test, when introduced, had been hailed as a satisfactory single test, but no single test had yet fulfilled that requirement.

[1] "The Treatment of Sewage Sludge by Bacterial Digestion."

[2] "Principles of Sewage Treatment." (Translated from the German by H. T. Calvert, M.Sc., Ph.D.) London. 1908.

The Author had made the rather sweeping statement that, "Some sewages, especially those containing trade-wastes, are much more amenable to sedimentation-tank treatment than are others." That depended very largely upon the nature of the trade-wastes. The Author had also suggested that chemical treatment of sewage was indicated when trade-wastes were present; but that again depended upon the nature of the trade-wastes, and Dr. Calvert would be loth to prophesy that the day of chemical treatment—especially for domestic sewage containing large amounts of matter in a colloidal state—was past; he did not think that that was the case.

The Author had justified his plea for more adequate purification of sewage-flows in excess of three times the average dry-weather flow. In his reference to detritus and grit-removal the Author had not referred to the possibility of utilizing the grit; but it could be readily cleaned by blowing air through it.

With regard to the design of the sedimentation tanks, to which Mr. Hetherington had also referred, the Author had illustrated a method which had been applied to even out the "flow", by which the head of sewage in the tank was raised or lowered. That was only a partial method of evening out the "strength" of the sewage. Dr. Calvert was acquainted with works where the strength of the sewage was evened out without losing any head, by the provision of a series of multiple inlets along the length of the tank; for instance, an inlet by which the strong sewage could be introduced halfway through the tank, so that it overtook the weak sewage which had entered the tank a considerable time before, and vice versa.

The subject of activated-sludge treatment had not come within the purview of the Royal Commission on Sewage-Disposal. Nobody had done more than the Author in contributing to the development of that method of sewage-purification, and his views deserved the closest study.

Mr. George Watson observed, with regard to the question of the utilization of sludge on the land, that he was old enough to remember the efforts made to defeat water-carriage by men who said that the land was being robbed of its rights by the sewage system. He considered that the Author was preserving nearly all of the valuable manurial constituents of the sewage in a more readily available and complete form than could ever have been achieved by any pail system. That system never dealt fully with the liquids, and those who recommended its use, because they could thus get manure back on to the land, would have lost much of the value. Digested sludge contained nearly the whole of the original manurial value and was free from grease, formerly the bugbear of farmers, which was now converted into valuable gas. The sludge was reduced on the Birmingham drying-beds to a content of only 35 per cent. of water. The Author had stated, that, at most towns, as a rule, farmers would not carry the sludge more than 2 or 3 miles, would pay very little or nothing for it, and would take it during only 6 or 8 weeks in the year, so that it

had to be stored. The reason appeared to be that the sewage works were at the mercy of a very small ring of customers, who simply took the sludge to suit themselves, and at their own price. If de-watering of the sludge were carried a little farther, which could easily be done by the available heat from the gas, and the sludge were reduced to powder, the manure could be carried long distances, so that one could get outside the ring. The question of soil fertility was of such importance that the treatment ought to be pursued to its logical conclusion by reducing the sludge to powder, so that it could be transported and distributed more widely. Sir Albert Howard, in his book, "An Agricultural Testament," had shown that, by having a really fertile soil on a farm controlled by him in India, he had obtained not only a double crop but also a very much better crop, from the point of view of quality, with the result that his animals were immune from disease. His cattle had actually come into contact with cases of foot-and-mouth disease without catching it.

Mr. David M. Watson observed that his only criticism of the Paper was that it was too short. Although true to its title, it did not cover all the ground implied thereby.

The most recent development dealt with was the theory of double or alternate filtration, with which was naturally associated partial treatment by one of the activated-sludge processes as a preliminary to filtration, and he inferred from the way in which the Author had treated the whole subject that the Author regarded that development as the main point to be emphasized in the Paper. The need for a complete understanding of the composition of the sewage and its preliminary treatment was of paramount importance if development were to continue. If those concerned with the problem were on the verge of finding that one of their old tools could be made to do more efficient service, they should study the theory of the use of that tool, and that was exactly what the Author was encouraging them to do.

Clogging of surface filters by colloidal and suspended matters in sewage was such a common complaint that it was doubtful whether the Author had emphasized it sufficiently. Probably it was no exaggeration to say that most filters suffered from that malady to some extent, but the trouble was not always discovered—certainly it was not diagnosed—until some visible ponding had appeared on the filter. It was, therefore, to be expected that treatment which eliminated the cause of the trouble would result in more efficient work by the filter. The Author's work in Birmingham, and also that of the Water Pollution Research Board, indicated that the enhanced efficiency would be well worth the trouble, and also the possible additional expense.

It had certainly been recognized for a number of years that the flocculation of colloids was the more efficient part of the duty of an activated-sludge plant, and that the less efficient part was the purification of the polluting matter in solution, whereas in the filter the reverse was the case.

Obviously, therefore, there was much to be said for a combination of the two processes, but it was a newer line of thought that the alternate filters might do the preliminary work for one another, and results which had so far come to Mr. Watson's notice clearly indicated that a great deal more had yet to be heard on that subject.

Reference had been made in the Paper to the responsibility of the high initial avidity of some sewages for oxygen for certain features of design in the activated-sludge plant. In the summer of 1939, when he had had the privilege of visiting some of the large sewage plants in the United States, he had seen two ingenious attempts to counter that initial avidity. The first was the Tallman's Island plant in the Borough of Queens, New York City, where there were two aeration units, each consisting of four channels traversed in series by the sewage. Each channel was 373 feet long by 20 feet wide. The flow was about 20 million gallons per day to each of the units, which had therefore a detention-period of 3½ hours with a sludge-return of about 20 per cent., but the sludge was admitted at one point only, namely, the inlet to the first channel. The sewage was admitted at the inlet to the first channel, at the inlet to the second channel, and at the inlet to the third channel, so that the load on the sludge was applied very gradually. Unfortunately the results of that plant were not then available, but it was claimed that a shorter detention-period was the result. The other attempt to solve the problem was made at the Southerly works of the city of Cleveland, Ohio, where the system of diffused air was referred to as tapered. In the first of the channels the diffusers were eight abreast, and at the far end four. Both the sewage and the sludge could be introduced either at the inlet end of the channel or at its far end. He believed that there were four channels in series. The result was, of course, that the first channel could be used solely for regeneration of the sludge, solely for pre-aeration of the sewage, or for a combination of the two in any proportions.

Mr. Harry Jackson observed that engineers in Birmingham were proud of the work of the Birmingham Tame and Rea District Drainage Board; in particular of their investigations, on scientific lines, of the conditions under which the various stages of purification worked themselves out. Those conditions known and reproduced in a plant, its success was assured.

In the experimental work upon the double-filtration plant it had been shown clearly that the control of the particular appliances in the various stages of purification—the detritus tank, the sedimentation tank, the percolating filter, and so on—so as to produce the conditions best suited for economical work, represented the best possible kind of design.

The Paper was valuable from another standpoint. Government Departments might be led by it to give attention to schemes of sewage purification designed to fulfil the conditions required for satisfactory working, rather than mere duplication of plants already in operation elsewhere.

If expressions in the Paper, such as "self-purification" and "the purifi-

cation-capacity of a percolating filter" could be clarified by the Author, its value would be enhanced.

Mr. L. F. Mountfort observed that for the bulk of the Paper he had nothing but praise, but there were a few points in connexion with percolating filters that he would like to raise.

The Author had illustrated the concept of "liquor-facility of treatment" by two examples, in the first of which he had compared the results of what might be called a synthetic sewage, containing all its impurities in the dissolved state and being treated on a laboratory filter, with the results of what Mr. Mountfort presumed was intended to be an ordinary sedimented sewage treated at an ordinary rate on the type of filter in use at Birmingham. He could not help thinking that the conclusions which the Author had drawn from that first experiment were to a certain extent obscured by the fact that his laboratory filter consisted of an exceptionally fine medium, whilst the other filter consisted of a medium about 1½ inch in size. In that experiment the Author had endeavoured to ascertain the effect of the removal of colloidal matter and of having all the impurities in solution. If one factor were varied in order to study its effect upon a result which depended on a number of factors, endeavour should be made, of course, to maintain all the other factors constant. In the case in question one filter contained a very fine medium indeed, whilst the other presumably contained a fairly large medium. Mr. Mountfort considered that, if the Author had been able to manufacture a synthetic sewage, in which the impurities were all in solution, and which was of the same strength as his ordinary sedimented sewage, and had then treated it on a filter of the same size, he would have been able to draw a much more satisfactory conclusion. Mr. Mountfort could not help thinking that the conclusion at which the Author had apparently arrived, namely, that if one had a filter dealing with ordinary sedimented sewage and could by some process substitute for that sewage a sewage of the same strength in which all the impurities were in solution, one could therefore treat the latter at three times the rate on the same filter, was hardly the conclusion to which the experiment would lead. He was much more impressed with the result of the second experiment, which definitely proved that on the same filter a greater liquor-facility of treatment could be obtained by the removal of some of the colloidal matter. If account were taken of the fact that the sewage had only about 70 per cent. of its previous strength, an improvement of at least 60 per cent. was still effected by the removal of the colloidal matter.

The Author had asserted that the size of the medium selected should depend upon the character of the liquid to be treated, but Mr. Mountfort considered that the method of distribution should also be taken into account. There was a vast difference between the kind of intermittent distribution produced by a continuous rotary sprinkler with dosing tank and a rectangular travelling distributor. The Author had stated that

filters filled with flints, unbroken quartzite, and other gravels, should have a cubic capacity 25 per cent. higher than that of filters filled with broken material. Mr. Mountfort had found that with gravel plus a rectangular travelling distributor, twice as much gravel as clinker was required to produce the same result.

He was very interested in the Author's statement in the introduction to the Paper, that the results of experiments with alternate filtration had already indicated a considerable improvement upon the original results obtained with single filtration.

He would like to point out, however, that the economic value of any method of improving the operation of a filter could not be judged entirely by confining consideration to the filter itself. If the improvement were obtained by altering the kind, as distinct from the quantity, of work which the filter was called upon to perform and by relieving it of work with which it was not well suited to deal, such work would have to be undertaken by some other portion of the plant, and any additional cost thus involved would need to be set against the improved economy of the filter

Dr. A. Parker observed that when the Water Pollution Research Board began an investigation of methods for the treatment and disposal of milk effluents it was soon found that the settled waste-water from dairies and creameries could not be satisfactorily treated in single percolating filters by the method ordinarily used by sewage-disposal works. Effluents of good quality were obtained for a time, but the filter gradually became clogged and inoperative. Long before that the Author and the late Mr. O'Shaughnessy had observed that filters which had been overloaded with sewage and were becoming clogged could be restored to a satisfactory condition by the application of a treated or partially-treated sewage liquor, and they had suggested that the Board should try treating milk effluents by using two filters in series and changing the order of those filters, the underlying idea being that any excessive quantity of solid matter deposited in the primary filter would be removed when that filter occupied the secondary position. Experiments were carried out on a large scale at a cheese factory over a period of several years, and were eminently successful. In the Paper the Author had given a load of 160 gallons per day per cubic yard of filtering medium for milk effluent with a B.O.D. of the order of 25 parts per 100,000. That figure allowed a margin of safety. In actual fact, during the summer months, when the load on the factories was greatest, 240 gallons of the liquid was treated per cubic yard of filtering medium. Dr. Parker would not suggest, however, that plants should be designed on that basis, because the experiments were very carefully controlled: such accurate control could not be expected under factory conditions, and he considered that the figure given by the Author should not be exceeded.

More recently, in the Board's laboratory at Watford, similar experiments had been carried out on a smaller scale with a mixture of sewage

and waste water of a kind discharged from factories recently erected in various parts of the country. Equal success had been achieved in dealing with those waste waters, and twice the load per cubic yard of filtering medium had been treated with the double-filtration system in comparison with single filters. The process was being applied on a large scale, and the result would be that a considerable amount of expense and material would be saved to the country. It was obvious that attempts should be made to ascertain whether the double-filtration method could be used with advantage in treating sewage at sewage-disposal works. The Author and his Board, with characteristic generosity and public spirit, had at once offered four percolating filters, and had provided all the additional equipment, such as settling-tanks and pumps. They had even built a laboratory, and the Water Pollution Research Board had been working at the Minworth works for more than 2 years. There was no doubt that at sewage works more than twice the load could be treated by the double-filtration system, and there was a possibility that even better results might be obtained by the use of, say, two filters as primary filters and one as a secondary filter, and by running those in a different order. The question of the cycle of change had also to be considered. A change once per week had been adopted, but there were indications from the biological work that some improvement might be effected by altering that period, possibly to once a day in the summer and once in 3 or 4 days in the winter. In order to assist in that work, the Author and his Board had erected eight smaller filters, each of which could hold up to 16 cubic yards, so that double or treble filtration could be used, or two could be run in parallel and one in series, or any other arrangement could be made, the size of the filtering medium and even the size of the filters being changed. It was hoped thereby to obtain useful information, and to supplement that with biological observations.

It appeared that sewage sludge ought to be used as a fertilizer. One difficulty was in drying it, distributing it, and applying it on the land, whilst another difficulty lay in ascertaining its real value. However, more interest was being taken in the matter. Through the Agricultural Research Council, experiments on the real fertilizing value of sewage sludge for different soils and different crops were being undertaken.

⁂ **Dr. S. H. Jenkins** believed that the time was opportune for reconsidering the principles underlying the design of sewage-disposal works, and the means for applying them. Many schemes for improving existing works were under consideration at the outbreak of the war, but with the altered conditions of a post-war period and the growing demand for improved town planning, such schemes might have to undergo drastic revision. Among the problems the future might bring to some works, the effect of admitting trade-effluent to the sewage might rank high in importance. Numerous commissions had urged the need for passing trade-

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⁂ This contribution, and also the following, were submitted in writing.

effluents into the public sewers as an important step in preventing river pollution. The Public Health (Drainage of Trade Premises) Act, 1937, allowed occupiers of trade premises to make application for the reception of trade-effluents into public sewers and, subject to certain safeguards, imposed an obligation upon local authorities to accept and treat the liquors. That measure, in spite of certain defects, was an important advance, which should help to mitigate pollution by industrial effluents, since the treatment of such effluents alone often failed to be effective through lack of adequate technical control or inherent difficulty in treatment. During recent years several trade-wastes formerly believed to be incapable of purification had been successfully treated in well-designed plants, but those plants were exceptional.

The presence of considerable quantities of some trade-wastes in sewage might affect the design of the works required to a far greater extent than might be foreseen from an examination of the usual figures of chemical analysis, and extreme caution was required in the interpretation of such data. For example, a waste which nearly neutralized the reserve of alkali in the sewage or added an appreciable quantity of chromium salts, would certainly limit, and perhaps stop, the formation of nitrate from the ammoniacal substances present in the sewage. Another instance, taken from actual practice, would aptly illustrate the burden sometimes imposed upon sewage-treatment plants by industrial wastes. A fairly weak domestic sewage required treatment in primary sedimentation tanks, followed by filtration in bacteria-beds at the rate of 100–200 gallons per 24 hours per cubic yard of medium, in order to produce an excellent, well-nitrated effluent. On the other hand, a highly industrial sewage, with a biochemical oxygen demand of similar order, but with a much higher figure for oxygen absorbed from permanganate, was treated by primary and secondary sedimentation, partial treatment with activated sludge, and filtration at the rate of 90–100 gallons per cubic yard, but yielded only partly-nitrated effluents of moderate quality.

The Author had referred to the method of partial activated-sludge treatment as one means of increasing the capacity of a bacteria-bed. Mr. S. J. Roberts and Dr. Jenkins[1] had recently demonstrated that about 15 per cent. of the impurity removed from sewage by activated sludge in 1 hour was removed by oxidation, whilst 85 per cent. was removed by coagulation, the coagulated solid matter becoming part of the sludge. Clearly it was the removal of solid matter by flocculation which permitted higher rates of filtration of partially-treated sewage. At the Minworth works, Birmingham, partial treatment with activated sludge for 1 hour had removed an average of 1,050 lb. of dry solid matter per million gallons of sewage treated during the year 1940. Under the most favourable con-

[1] "Studies on Activated Sludge: I, Flocculation and Oxidation of Sewage Solids." Journal Soc. Chem. Ind., vol. lviii (1939), pp. 225–29.

ditions of quiescent sedimentation it would be possible to remove from that sewage no more than 390 lb. of dry matter per million gallons.

With regard to the use of sewage sludge as a manure, the general opinion of users appeared to be that it was a slow-acting fertilizer, although its value varied from one works to another, and also according to the type of land to which it was applied. It seemed to be especially suitable for light soils deficient in organic matter, and that view had been confirmed by the results of field experiments carried out by the Midland Agriculture College with air-dried sludge which had undergone decomposition in lagoons. Those trials showed that the yields of market-garden crops were increased by the application of sludge fortified with artificial fertilizers. No serious efforts had yet been made in England to dry activated sludge without the loss of its fertilizing constituents. A product like activated sludge, containing 5–8 per cent. of nitrogen and 75–85 per cent. of organic matter, would find as ready a market in England as in the United States, where commercial dryers were being installed in many works.

Mr. Edward Halliwell agreed with the principles advocated by the Author for the design of sewage works. He wished specially to emphasize the importance and necessity of balancing the volume and equalizing the strength of the day- and night-flow of sewage, which gave rise to many of the difficulties in sewage treatment. He agreed also as to the advisability of removing, as far as possible, the suspended impurities before passing the effluent on to the percolating filters or into the aeration tanks of the activated-sludge plant. He considered that bacteria and organisms had enough work to do in purifying the dissolved organic impurities without expending time and energy in the purification of suspended organic solids, which ought to be settled as sludge, in the tanks.

The Author, in reply, remarked that, bearing in mind the crude methods of distribution adopted in the early filter experiments, Mr. Hetherington's account of the origin of the first contact-bed was probably historically accurate.

The nature of the water-supply in the drainage-area had a bearing upon sewage treatment, a hard water being preferable to a soft water in assisting flocculation in the sedimentation tanks, and in providing some of the alkali reserve which, as mentioned in the Paper, served a useful purpose in the subsequent biochemical oxidation of the nitrogenous substances present in sewage.

The alkalinity in domestic sewage from an area using soft water might amount to 30 parts per 100,000, and that quantity was sufficient for all demands made to neutralize the nitric acid produced during biochemical oxidation of the settled sewage. From that it would be seen that the additional alkalinity which would be available when a hard water was used for supply purposes was of more service in a sewage containing trade-wastes of an acid character, than if the sewage were solely of domestic origin.

The Author agreed with Mr. Hetherington that all storm-water sewage delivered to the sewage works in excess of three times the average daily dry-weather-rate of flow should receive some form of treatment.

In the Author's view, serious river pollution at the present time came from storm-water sewage overflows in large urban areas, and an examination of some of the sewerage systems would disclose that many of the older storm-water overflows came into action at rates of flow much lower than the six-times limit.

A large sewerage system offered better safeguard against the too-frequent operation of storm overflows if the branch intercepting-sewers and their storm overflows were designed on a more generous scale, in terms of their dry-weather flow, than the main sewer into which they discharged.

The Author advocated disintegration of screenings as a part of the usual equipment of the larger inland works, in order to ensure that the screenings should be returned to the sewage and subsequently dealt with as part of the sludge in a less objectionable manner than by disposal separately.

Disintegration of screenings as part of a sea-outfall scheme in no way reduced pollution, although it did reduce the food-supply of seagulls.

With regard to detritus tanks, the Author was of opinion that the general tendency was to make them too large, and to provide them with needlessly elaborate grit-removal apparatus. He agreed with Mr. Hetherington that only on very rare occasions in the larger installations could the detritus tank be dispensed with.

The remarks of Mr. Hetherington regarding the capacity of storm-water tanks for very large drainage-areas illustrated one of the advantages of regional drainage-control as exemplified in the West Middlesex works, and to a smaller degree in Birmingham, where the main sewers had less margin for storage and the balancing of sudden storm-water discharges.

The Author was in agreement with Dr. Calvert as to the value of research in matters affecting sewage purification, and was thankful that the work of the Water Pollution Research Board, unlike that of the Royal Commission on Sewage Disposal, had been allowed to continue in wartime.

Even now Dr. Dunbar's textbook on the Principles of Sewage Treatment (to which Dr. Calvert had referred) was of outstanding value. It should not be forgotten, however, that the Proceedings of The Institution contained valuable Papers and discussions upon that subject. A study of some of the earlier Papers disclosed how near to modern discoveries were some of the engineers and chemists of 50 or 60 years ago.

In making the statement that "Some sewages, especially those containing trade-wastes, are much more amenable to sedimentation-tank treatment than are others," the Author had had in mind cases in which certain trade-wastes, by themselves or in combination with others, provided excellent sewage precipitants, and thus counterbalanced their ill

effect by improving purification action in the sedimentation-tanks, instead of merely increasing the strength of the sewage into which they discharged.

Dr. Calvert had referred to a method of evening the strength of the sewage, without loss of head, by the provision of multiple inlets in the length of the sedimentation-tank. That method was of value in averaging the strength of the daily flow, but did not possess the two-fold advantage of averaging strength and rate of flow as illustrated in the Paper (*Fig.* 6).

The Author was interested in Mr. George Watson's views regarding the treatment and disposal of sewage sludge. He would not, however, ascribe the farmers' reluctance to take delivery of sewage sludge at all times of the year to purely selfish motives, but rather to the fact that their business of farming was strictly controlled by its seasonal variety of operations and weather conditions. The farmer naturally desired to have the sewage sludge when he had the labour and transport available, and could get the material on to the land.

In reply to Mr. David Watson's criticism that the Paper was too short, the Author took refuge behind the general desire of members for Papers of moderate length, and his own opinion that such Papers were more likely to succeed in their object, by promoting an exchange of views, than were those of greater length. Mr. Watson was correct in surmising that the Author regarded the improvement in efficiency of the percolating filter by the use of double or alternate filtration as the main point of emphasis in the Paper.

The research work at Minworth, Birmingham, which was being carried out by the Water Pollution Research Board, had advanced sufficiently far to enable it to be said that by a simple modification in the method of operating percolating filters, their efficiency, as measured by their ability to purify settled sewage per cubic yard of medium by single filtration, might be doubled; and that that might be done cheaply was obvious from the facts that the only additional items of capital expenditure related to larger humus-tanks, supply-pipes, distributors, and a pumping-plant.

The quantity of energy for pumping to obtain the double filtration was, in most cases, likely to be moderate, and was about one-half of the energy consumed in a bio-flocculation plant carrying out a corresponding amount of work, namely, flocculating sedimented sewage to such a degree that it might be purified by single filtration at double the rate of plain sedimented sewage.

The reasons for the enhanced efficiency of a percolating filter when used alternately as a primary and secondary filter, in comparison with the original method of single filtration, had yet to be established, but two facts relating to the retention and discharge of humus might have important bearings upon the differences in performance under the two methods.

Graphs illustrating the yearly discharge of humus from single percolating filters and from corresponding filters working in series with alternate

charges in their order, showed that in the first instance the discharge might be indicated by a smooth curve with two large humps in the spring and the autumn respectively, when the discharge of humus was at its maximum, whilst the discharge from the alternating filters was represented by a regular zig-zag line corresponding to the alternating periods of the filters.

It was thus obvious that whilst the single filter cleansed itself twice annually, the alternating filters working in a fortnightly cycle discharged their excess humus twenty-six times.

Most filters suffered from the malady of surface clogging, which in itself imposed a mechanical check upon the quantity of liquid which could be applied to the surface, and produced other ill-effects, such as lack of aeration and unequal distribution of the liquid.

It was probable that the higher efficiency of the alternating filters over single filters was due largely to the better control of surface clogging afforded by that method.

The Author was interested to hear of the means adopted at New York and at Cleveland, Ohio, to counter the ill-effects of the high initial avidity of some sewages for oxygen, and looked forward to reading an account of the experiments on their conclusion.

The Author regretted that Mr. Jackson regarded such expressions as "self-purification" and "the purification-capacity of a percolating filter" as insufficiently clear. "Self-purification" of a polluted liquid or river might be defined as the ability of the liquid or river to purify, or partly purify, itself by natural means without outside assistance. "The purification-capacity of a percolating filter" was usually expressed in terms of gallons of liquid purified per cubic yard of filter medium per 24 hours, and might vary in amount in inverse ratio to the strength of the liquid, and to the degree of purification achieved. It was also affected, as described in the Paper, by several factors connected with the construction of the percolating filter, the method of distribution, and the temperature in the filter.

The Author had studied Mr. Mountfort's criticism of the experiment illustrating the "liquor facility of treatment" of a synthetic sewage containing all its impurities in a dissolved state, as compared with a liquid containing an equal load in a mixture of suspended and dissolved impurity, and could not agree that a difference in the size of medium employed in the two experiments affected the permissible inference. Each size of medium was the most favourable for the respective liquids treated, and to have employed a small medium for the liquid containing suspended impurity would have been just as unfair to that liquid as the employment of a $1\frac{1}{2}$-inch medium for the liquid containing only dissolved impurity.

The Author agreed with Mr. Mountfort that the method of distribution to be employed should be taken into account in assessing the capacity of a percolating filter, and had stated that in the Paper.

The Author's experience with continuous rotary sprinklers and rect-

angular travelling distributors had left him with the conviction that there was no perceptible difference between the results obtained from the best of both types, although there was wide variation in the results obtained from various patterns of rotary sprinklers.

Mr. Mountfort's remarks regarding the reduced efficiency of gravel and flint medium, in comparison with clinker, tended to confirm the Author's views; the difference in degree of the respective results obtained by Mr. Mountfort and the Author were probably due to dissimilar types of distribution and size of medium employed.

The Author was indebted to Dr. Parker for placing on record a clear account of the circumstances which led to the development of the double-filtration system. Considerable scientific work still remained to be done to round off the investigation; but the results so far obtained had been upon a sufficiently large scale and covered a period sufficient, in the Author's view, to justify further development of the new system, not only in the extension of old works already using single filtration, but also for the design of new works.

The remarks of Dr. Jenkins regarding the influence of certain trades wastes upon sewage treatment tended to emphasize the views expressed in the Paper, and by Mr. Hetherington, as to the necessity of "finding out what it was one had to deal with before starting to deal with it."

The interesting comparison made by Dr. Jenkins of the removal of dry solid matter from sedimented sewage by flocculation with activated sludge, as compared with the results obtained by quiescent sedimentation, confirmed similar findings by the late Mr. F. R. O'Shaughnessy, who might be said to have been one of the pioneers of the bio-flocculation process.

The Author agreed with Dr. Jenkins regarding the desirability of a more general use of sewage sludge as a manure; but he would point out that the conversion of wet activated sludge into a dry form at a reasonable cost, and without materially reducing its fertilizing value, formed a very difficult problem, and one that could not yet be said to have been solved in an economical manner. Surplus activated sludge formed a comparatively small proportion (about one-fifth) of the total sludge-production of a sewage purification works employing that method of treatment, and it was only in a very large works that a separate method of conversion into a dry manure would appear to deserve consideration.

The Author was indebted to Mr. Halliwell for underlining some of the more important views expressed in the Paper.

Paper No. 5241.

"The Effect of Earthquakes on Framed Buildings."

By ALLAN JOSHUA OCKLESTON, B.E., Ph.D., Assoc. M. Inst. C.E.

(Ordered by the Council to be published with written discussion.) [1]

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INTRODUCTION.

IN countries subject to violent seismic disturbances the design of buildings is considerably affected by questions of earthquake resistance. In the generally accepted method of design it is assumed that earthquake motion, an irregular vibration, can be represented by a constant horizontal acceleration. This assumption could be justified if the periods of earthquake motion were appreciably greater than the fundamental period of the structure. The range of possible earthquake periods, however, includes the fundamental periods of all normal buildings, and the possibility of resonance, for at least a few cycles, is by no means remote. For this case the validity of the simple design assumption appears doubtful, and no justification seems to have been advanced for its use.

When the period of the ground motion and the natural period of a structure are of the same order, the determination of the stresses induced is a dynamic problem; its solution requires a knowledge of both the nature of earthquake motion and the nature of the structure considered as a vibrating system.

THE NATURE OF EARTHQUAKE MOTION.

A knowledge of the nature and intensity of the motion in the meizoseismal areas of destructive earthquakes must form the basis of any

[1] Correspondence on this Paper can be accepted until the 15th July, 1941, and will be published in the Institution Journal for October 1941.—SEC. INST. C.E.

rational method of earthquake-resistant design. Few reliable records of such motion have been obtained, but the general form appears to be similar in all cases [1–5]. The motion can be described as an irregular three-dimensional vibration, the path of a point on the surface being roughly ellipsoidal, often with abrupt changes in direction. The movement is, as a rule, mainly horizontal.

Records of a horizontal component of earthquake motion begin with rapid preliminary tremors of very small amplitudes giving relatively small accelerations. A sudden large increase in amplitude marks the beginning of the principal motion, which may last for several minutes, though the intensity has usually decreased considerably by the end of the first minute. The principal motion may be regarded as a series of main waves of large amplitudes and periods on which are superimposed secondary waves of smaller amplitudes and shorter periods. The amplitudes and periods usually vary continuously, but a succession of several similar waves may occur [5, 6]. The periods of the main waves are generally from 1 second to 2·5 seconds, although periods up to 5 seconds have been observed. The periods of the secondary waves range from less than 0·1 second to about 1 second. The secondary waves give rise to large accelerations ; these are often comparable with, and sometimes exceed, the accelerations of the larger but slower main waves.

In a series of observations made at the Earthquake Research Institute in Tokyo it was found that, irrespective of the intensity of the earthquake and of the distance of the epicentre, the periods of the secondary waves, which gave the greatest accelerations, were limited to a narrow range of 0·3–0·4 second, although the periods of the main waves differed widely [3, 7]. Similar observations made on alluvial ground gave evidence of three such prevailing periods, namely 0·7–0·9 second, 0·4–0·45 second, and 0·2–0·3 second, whilst prevailing periods ranging from less than 0·1 to 0·3 second are found in records of some American earthquakes [5, 8]. It has been suggested that every locality has certain natural periods of vibration, and that the secondary waves in earthquake motion are the result of these natural vibrations of the earth's crust, which are likely to be harmonic in form [3, 7, 9].

Less information is available regarding the vertical component of earthquake motion, but this appears to be of the same form as the horizontal component. The three vertical accelerograph records of the Long Beach earthquake are similar. That obtained at Long Beach is described as a train of waves of 1·0–1·5-second period upon which secondary waves of 0·1–0·2-second period are superimposed, the greatest accelerations being given by these secondary waves [5]. In the immediate vicinity of the epicentre, earthquake motion may be predominantly vertical, but the relative magnitude of the vertical component appears to decrease rapidly

[1–5] The references are to the bibliography on pp. 63, 64, *post*.

with distance from the epicentre [5, 6, 10]. In most of the area affected by an earthquake the motion is mainly horizontal [1–4].

Attention is directed here to the nature of earthquake motion rather than to its possible intensity, usually measured by the maximum horizontal acceleration of the motion. It may, however, be noted that the maximum accelerations are often much greater than the value, $0{\cdot}1g$, commonly used in design. Accelerograph records of earthquakes not of the greatest intensity have shown [5, 11] maximum accelerations of $0{\cdot}13g$–$0{\cdot}23g$, whilst those of great earthquakes have been estimated [2, 8, 12] at $0{\cdot}4g$–$1{\cdot}0g$. Considerable local variations in intensity have been observed. The nature of the soil appears to be largely responsible, the intensity being much greater on soft ground than on rock [1–4]. Experiments have shown that in soft soil the amplitude of the motion may be increased and the form of the waves changed, giving considerably increased accelerations [13].

Some observations made by J. Milne [14] indicated that at a distance from the epicentre earthquake motion was largely superficial, and that a structure surrounded by a deep trench would be effectively isolated from the movement. Subsequent investigations have shown that the intensity decreases but little with depth [3, 15].

As large vertical movements are of local occurrence, and as a building has a greater margin of safety for vertical than for horizontal accelerations, the horizontal component of earthquake motion is generally considered to be the chief cause of destruction. This horizontal component is an irregular vibration, the periods of which may range from 0·1 second to 5 seconds. The occurrence of a long-continued series of waves of the same period is unlikely, but not infrequently two or three successive waves have approximately the same period.

The Behaviour of Buildings during Earthquakes.

Experimental investigations of the lateral vibration of buildings have usually been confined to the determination of the periods of free vibration [3, 16]. The fundamental periods of buildings up to about 100 feet in height generally range from 0·3 to 0·8 second; those of taller structures seldom exceed 1·6 second, although a period of 2·32 seconds has been observed. The periods of higher modes of vibration may be less than 0·1 second. The vibration of buildings is generally due to the elasticity of the structure, but there is some evidence that buildings on soft soil may rock as a whole on the yielding foundation [3, 4].

Seismograph records have shown that during earthquakes there is no material difference between the motion of the foundation of a building and that of the neighbouring ground [3]. Since the range of possible earthquake periods includes the fundamental periods of all normal buildings, resonance may occur. Long-continued resonance is unlikely, but two or three waves of equal period may cause large deflexions [17, 18, 19]. Records

obtained during earthquakes show that the motion of the top of a building is generally much greater than that of the foundation [3, 20], and in some cases there is evidence of resonance [21].

In earthquake regions buildings are generally made as rigid as possible, partly with the object of making the free periods less than any earthquake period. The greatest accelerations in some earthquakes have, however, been due to secondary waves of 0·1–0·3-second period [5, 11], whilst the fundamental periods of buildings are seldom less than 0·3 second. For tall buildings flexible first-storey construction, in which the first-storey stanchions are slender and the upper part of the structure is as stiff as possible, has occasionally been used [8, 22]. The fundamental period of such a building would be large, but earthquake periods may be as great as 5 seconds and it is doubtful if the possibility of resonance can be avoided by this means; the possibility of resonance with a higher mode must also be considered. Non-linear restoring forces have been suggested to prevent large deflexions at resonance, but no buildings of this type appear to have been constructed [19, 23]. Single-storey buildings have been effectively isolated from earthquake motion by steel shot between the superstructure and the foundation [1, 14]. Such free foundations have not been used for taller structures, although it has been suggested that a layer of gravel might have the same effect [24, 25].

As the possible periods of horizontal motion during earthquakes include the periods of free lateral vibration of all normal buildings, resonance may occur for a few cycles at least. This possibility must be considered in any rational method of earthquake-resistant design, and a knowledge of the lateral vibration of buildings [25, 26] is a necessary preliminary to the development of such a design method.

The Lateral Vibration of Building Frames.

Unless sweeping simplifying assumptions are made, the effects of which cannot easily be gauged, mathematical analysis of the lateral vibration of multi-storey building frames is so laborious as to be impracticable. The analysis of simpler frames is possible without recourse to such assumptions, and the behaviour of simple frames can throw considerable light on that of more complex structures.

A general method of analysis is given here. To simplify the expressions, a two-storey plane frame is considered, and the masses on the frame are assumed to be concentrated at the floors. A simple-harmonic ground-motion is assumed, as it has been found that the same general conclusions can be drawn from a simple harmonic motion as from an irregular vibration similar to earthquake movement [19]. Since maximum horizontal acceleration is generally adopted as a measure of earthquake intensity, the magnitude of the ground-motion is defined by its maximum acceleration.

In any two-storey building frame (*Fig. 1*) :

W_1, W_2 denote the masses on Floors 1, 2 ;

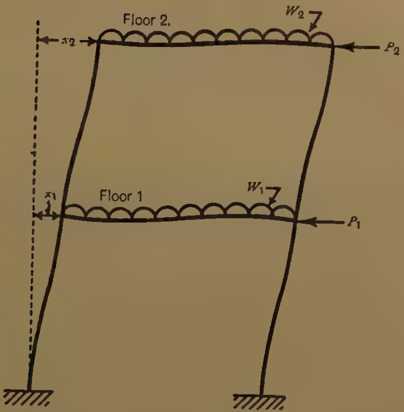
M_1, M_2 $= \frac{W_1}{g}, \frac{W_2}{g}$, where g is the gravitational acceleration ;

$\delta_{1.1}$ denotes the horizontal deflexion of Floor 1 due to a unit horizontal force at Floor 1 ;

$\delta_{1.2}$,, the horizontal deflexion of Floor 1 due to a unit horizontal force at Floor 2 ;

$\delta_{2.2}$,, the horizontal deflexion of Floor 2 due to a unit horizontal force at Floor 2.

Fig. 1.



If the frame is deflected so that the displacements of Floors 1 and 2 relative to the base are x_1 and x_2, forces P_1 and P_2 will be induced at the floors tending to restore the frame to its equilibrium position. These forces are :

$$P_1 = cx_1 - bx_2, \quad P_2 = -bx_1 + ax_2 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where :

$$a = \frac{\delta_{1.1}}{\delta_{1.1}\delta_{2.2} - \delta_{1.2}^2}, \quad b = \frac{\delta_{1.2}}{\delta_{1.1}\delta_{2.2} - \delta_{1.2}^2}, \quad c = \frac{\delta_{2.2}}{\delta_{1.1}\delta_{2.2} - \delta_{1.2}^2}.$$

The deflexions x_1, x_2 are assumed to be those due to a periodic displacement of the base :

$$\frac{\alpha}{p^2} \cos pt$$

having a maximum acceleration of $-\alpha$. If, at this stage, the damping forces are neglected, the equations of motion for the frame are :

$$\left.\begin{aligned} \ddot{x}_1 + \frac{c}{M_1}x_1 - \frac{b}{M_1}x_2 &= \alpha \cos pt \\ \ddot{x}_2 - \frac{b}{M_2}x_1 + \frac{a}{M_2}x_2 &= \alpha \cos pt \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The solution of these simultaneous differential equations is simplified by the use of the normal co-ordinates :

$$u=x_1-\frac{x_2}{\eta'} \text{ and } u'=x_1-\frac{x_2}{\eta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

where

$$\begin{bmatrix}\eta \\ \eta'\end{bmatrix}=\frac{2bM_1}{aM_1-cM_2\pm\sqrt{(aM_1-cM_2)^2+4M_1M_2b^2}}$$

In terms of the normal co-ordinates the equations of motion are :

$$\left.\begin{aligned}\ddot{u}+n^2u&=\left(1-\frac{1}{\eta'}\right)\alpha\cos pt\\ \ddot{u}'+n'^2u'&=\left(1-\frac{1}{\eta}\right)\alpha\cos pt\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (4)$$

where

$$\begin{bmatrix}n^2 \\ n'^2\end{bmatrix}=\frac{1}{2M_1M_2}\left\{aM_1+cM_2\mp\sqrt{(aM_1-cM_2)^2+4M_1M_2b^2}\right\}$$

For a particular frame and loading, η, η', n, and n' are constants.

Allowance can conveniently be made for the effects of damping. When the damping is due to the internal friction of elastic materials, the usual assumptions of viscous damping, and of damping proportional to the rate of change of stress, lead to results inconsistent with experimental data. Experiments on various metals and certain other materials have shown that for the normal range of stresses the decay of free vibration is approximately logarithmic ; the logarithmic decrement is equal to ξE, where ξ is an internal-friction constant and E the elastic modulus for the material [27]. If the equations of motion for a system with internal-friction damping are modified by including in each normal equation a term proportional to the first derivative of the appropriate normal co-ordinate and to the speed of the corresponding mode, the solution will be in accordance with the experimental results.

The equations of motion for the two-storey frame, modified to include the effects of internal friction, are :

$$\left.\begin{aligned}\ddot{u}+2kn\dot{u}+n^2u&=\left(1-\frac{1}{\eta'}\right)\alpha\cos pt\\ \ddot{u}'+2kn'\dot{u}'+n'^2u'&=\left(1-\frac{1}{\eta}\right)\alpha\cos pt\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

where $$k=\frac{\xi E}{2\pi}$$

In all practical cases n^2 and n'^2 are real and positive, and the solution is :

$$\left.\begin{aligned} u&=e^{-nkt}A\cos(nt\sqrt{1-k^2}+\theta)\\ &\quad+\frac{\left(1-\frac{1}{\eta'}\right)\alpha}{(n^2-p^2)^2+4k^2n^2p^2}\{(n^2-p^2)\cos pt+2knp\sin pt\}\\ u'&=e^{-n'kt}A'\cos(n't\sqrt{1-k^2}+\theta')\\ &\quad+\frac{\left(1-\frac{1}{\eta}\right)\alpha}{(n'^2-p^2)^2+4k^2n'^2p^2}\{(n'^2-p^2)\cos pt+2kn'p\sin pt\}\end{aligned}\right\} \quad . \quad . \quad (6)$$

or, in terms of the displacements of the floors :

$$\left.\begin{aligned} x_1&=re^{-nkt}\cos(nt\sqrt{1-k^2}+\theta)\\ &\quad+r'e^{-n'kt}\cos(n't\sqrt{1-k^2}+\theta')+R_1\alpha\cos(pt-\epsilon_1)\\ x_2&=\eta re^{-nkt}\cos(nt\sqrt{1-k^2}+\theta)\\ &\quad+\eta'r'e^{-n'kt}\cos(n't\sqrt{1-k^2}+\theta')+R_2\alpha\cos(pt-\epsilon_2)\end{aligned}\right\} \quad . \quad . \quad (7)$$

A, A', θ, θ', r, and r' are determined by the initial conditions, whilst R_1, R_2, ϵ_1, and ϵ_2 are, for a given frame and loading, functions of p.

The configuration of the frame for each of the two normal modes of free vibration is defined by the ratio of the floor displacements, the ratio for the fundamental, η, being positive, and that for the second mode, η', negative. The decay of free vibration is logarithmic, the logarithmic decrement being

$$\frac{\xi E}{\sqrt{1-k^2}}$$

for both modes. As k is small in comparison with unity, this is in accordance with the results of experiment. From the form of the forced-vibration terms in equation (6) it is likely that for ground motions of equal maximum acceleration the displacements of the frame at resonance with the second mode will be small in comparison with those at resonance with the fundamental.

In this analysis the masses on the frame are assumed to be concentrated at the floors. If the configuration of a frame during vibration is known, allowance can be made for the masses carried by the stanchions by a method similar to Rayleigh's approximation for free periods. Four frames have been considered, all of equal storey-heights and with equal floor-loads, and having continuous stanchions encastered at the base :

(i) A two-storey frame, with beams pinned to the stanchions.
(ii) The two-storey model-frame used in the experimental work.
(iii) A two-storey frame with rigid beams rigidly connected to the stanchions.
(iv) A three-storey frame similar to frame (iii).

The masses at the floors having the same effect as masses w per storey uniformly distributed along the stanchions have been calculated for the fundamental and second modes, on the assumption that the configuration is not materially affected by the stanchion masses (Table I).

TABLE I.—MASSES AT FLOORS EQUIVALENT TO STANCHION MASSES.

Frame.	Fundamental mode.			Second mode.		
	Floor 1.	Floor 2.	Floor 3.	Floor 1.	Floor 2.	Floor 3.
(i)	1·29 w	0·31 w	—	0·73 w	0·55 w	—
(ii)	1·14 w	0·40 w	—	0·69 w	0·16 w	—
(iii)	1·00 w	0·43 w	—	0·65 w	0·21 w	—
(iv)	1·04 w	0·88 w	0·46 w	0·78 w	0·99 w	0·28 w

It seems likely that for normal frames, where the floor loads form the greater part of the total load, satisfactory results could be obtained by assuming the mass carried by a stanchion to be concentrated, half at the floor below and half at the floor above. This assumption would be less accurate for the second mode than for the fundamental. The amplitude of the second mode will, however, generally be smaller than that of the fundamental. Large amplitudes of forced vibration are likely only for periods of the same order as that of the fundamental; for such periods the configuration differs little from the fundamental configuration.

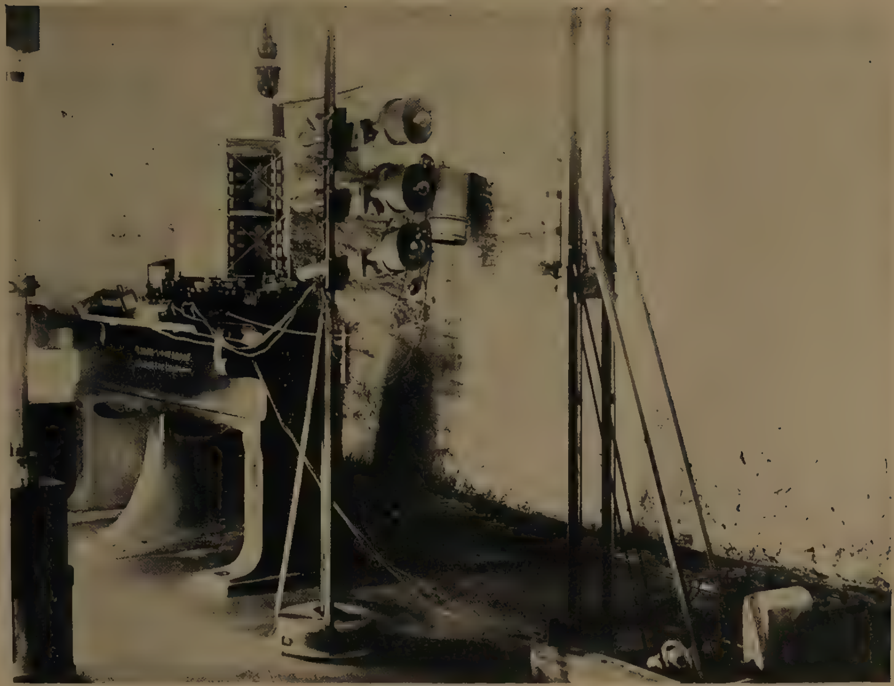
Only plane frames have been considered here; but the analysis can also be applied to space frames by resolving the ground movement into its components parallel to the axes of the structure, if the frame and loading are symmetrical so that there is no torsion, and if the floors are sufficiently stiff to prevent relative movement of the stanchions at the floors. Examination of buildings damaged by a hurricane indicated that floors of normal construction are sufficiently stiff to prevent such movement [28].

THE VIBRATION OF A MODEL OF A BUILDING FRAME.

An experimental investigation of the lateral vibration of a model building-frame was made to check the general analysis, and to determine the possible accuracy of such tests. A general view of the apparatus used is given in *Fig. 2*.

The model, a two-storey single-bay frame, is shown in *Fig. 3*. It was formed of two side-frames machined from ¼-inch steel plate and braced together at the ends, weights being clamped to the members to represent the masses carried by the beams and stanchions. The base of the frame was fastened by heavy clamps to the vibrating plate of a shaking-table. The vibrating plate rested on ball-bearing rollers, and moved between ball-bearing roller guides. A spring kept it in contact with a cam, a

Fig. 2.



GENERAL VIEW OF APPARATUS.

Fig. 3.

MODEL-FRAME WITH BEAM AND STANCHION LOAD.

large-diameter ball-bearing eccentrically mounted, which was driven by a variable-speed electric motor. A heavy flywheel was fitted to the motor-shaft to reduce speed variations to a minimum. The movement of the vibrating plate approximated very closely to simple harmonic motion.

Light knife-edged rockers carrying small mirrors were fitted between V-bearings at the floors of the frame and similar bearings carried by stiff aluminium panels clamped to the vibrating plate. A similar rocker and mirror arrangement was used to measure the movements of the base. Continuous photographic records of the displacements of the floors and of the base were obtained by beams of light reflected by the tilting mirrors and focused on to bands of film on a rotating drum. On one band a time-scale was provided by a style operated by 50-cycle alternating current, which scratched a 100-cycle wave, clearly visible after development, on the emulsion of the film. The periods and amplitudes of the movements were obtained from these photographic traces.

Before the vibration tests were made, the deflexions of the model due to horizontal forces at the floors were determined to check the assumptions on which the calculations were based, that the joints were rigid and the stanchions encastered. As the observed and the calculated values agreed very closely, the greatest discrepancy being only 2·2 per cent., the calculated deflexions were used in all subsequent calculations.

To gauge the magnitude of the errors introduced by the assumption that the mass on a stanchion length could be assumed to be concentrated, half at the floor below and half at the floor above, two series of vibration tests were carried out. In one, only the beams were loaded; in the other, both beams and stanchions were loaded, the stanchion loads amounting to 26 per cent. of the beam loads.

In the free-vibration tests the vibrating plate carrying the model was firmly clamped to the bed of the shaking-table. Light cords fastened at the floors of the model were passed over pulleys, and weights were attached. These weights were adjusted until the ratio of the floor displacements equalled the calculated ratio for one of the normal modes, so that this mode would be excited if the frame were suddenly released. The cords were cut simultaneously and photographic traces of the floor movements were taken. The procedure in the determination of the damping constants was similar, except that the recording drum was rotated more slowly, so that the vibrations were recorded for a sufficiently long time for the amplitudes to have decreased appreciably.

Although the initial loading was arranged to excite only one normal mode, components of both were found in most records. Where the loading had been arranged to excite the fundamental, the second-mode component was always small; in the second-mode traces the fundamental component was relatively larger. The periods and ratios of displacements could, however, be found with considerable accuracy, the greatest discrepancy between any one determination and the mean for that case being

about 2 per cent. More difficulty was experienced in obtaining consistent values of the damping, particularly for the second mode, as the relative magnitude of the fundamental component increased with time. The internal-friction constant is, moreover, proportional to the logarithmic decrement, and a small error in amplitude can lead to a considerable error in logarithmic decrement.

In Table II the mean observed periods and ratios of floor displacements are compared with the calculated values.

TABLE II.—PERIODS AND RATIOS OF FLOOR DISPLACEMENTS.

	Fundamental mode.		Second mode.	
	Period.	Ratio of displacements.	Period.	Ratio of displacements.
		Beams loaded		
Observed value	0·0965 second.	+2·16	0·0286 second.	−0·471
Calculated value	0·0973 second.	+2·15	0·0290 second.	−0·472
Difference	0·8 per cent.	0·5 per cent.	1·4 per cent.	0·2 per cent.
		Beams and stanchions loaded.		
Observed value	0·1033 second.	+2·11	0·0304 second.	−0·510
Calculated value	0·1042 second.	+2·12	0·0321 second.	−0·528
Difference	0·9 per cent.	0·5 per cent.	5·3 per cent.	3·4 per cent.

The agreement is close, being within 1·4 per cent. except for the second mode when both beams and stanchions are loaded; for this case the discrepancies are 5·3 per cent. and 3·4 per cent. This rather poorer agreement may be attributed to the fact that the assumption regarding the stanchion masses is less accurate for the second mode than for the fundamental.

The mean observed values of the internal-friction constant are given in Table III.

TABLE III.—VALUES OF THE INTERNAL-FRICTION CONSTANT.

	Internal-friction constant: inches² per lb.	
	Fundamental mode.	Second mode.
Beams loaded	$1{\cdot}55\times10^{-10}$	$2{\cdot}99\times10^{-10}$
Beams and stanchions loaded	$2{\cdot}10\times10^{-10}$	$2{\cdot}27\times10^{-10}$

In comparison with the values of ξ found from tests on uniform rods [27], namely, $1{\cdot}62\times10^{-10}$ to $1{\cdot}83\times10^{-10}$ inches² per lb., those for the frame are rather high, but the four values are of the same order, and the agreement is sufficiently close to show that the law of damping assumed is not seriously in error.

In the forced-vibration tests a simple harmonic motion was imparted to the base of the model-frame by the shaking-table. When a steady state was reached photographic traces of the movements of the floors and of the base were taken. In each series of tests, with beams loaded, and with both beams and stanchions loaded, the amplitude of the base-motion was kept constant and the floor displacements were found for a considerable range of periods.

A comparison of the observed and calculated maximum displacements is given in *Figs. 4*. In most of the tests the differences between the observed and the calculated values are less than 5 per cent. When both beams and stanchions are loaded the displacements of the lower floor for periods approaching that of the second mode do not agree so closely; this is probably due to the assumption made in the calculations regarding the effect of the stanchion masses. For these periods the displacements of the lower floor are small in comparison with those of the upper floor, and there is little difference between the bending moments derived from the observed displacements and from the calculated displacements.

It is evident from the experimental results that the general analysis gives an accurate estimate of the behaviour of frames during lateral vibration, and that the assumptions regarding the stanchion masses and the nature of the damping do not lead to serious errors. The consistency of the observed values shows that model-analysis forms a reliable means of investigating the vibration of structures.

The Effect of Earthquakes on Building Frames.

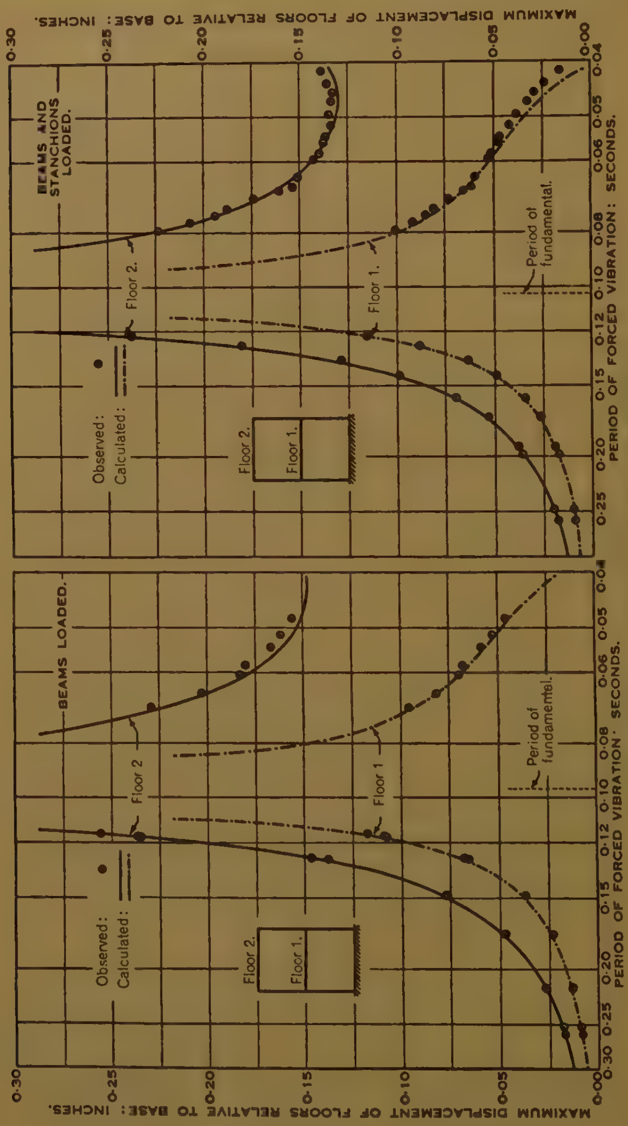
The behaviour of building frames subjected to periodic ground movements can best be studied by considering particular cases. A two-storey single-bay frame, frame A, the prototype of the model used in the experimental work, is considered. For the loading assumed, the periods of the fundamental and second modes are 0·418 and 0·129 second respectively, and the ratios of the floor displacements for these modes are +2·12 and −0·528. The damping constant ξE is taken as 0·3, this being based on the damping constants deduced from observations of the vibration of certain structures (Table IV).

Table IV.—Observed Damping Constants.

Structure.	Damping constant ξE.
Steel-framed buildings [29]	0·315 and 0·788
Reinforced-concrete building [29]	0·307 to 0·405
,, ,, frame [30]	0·26
,, ,, chimneys [29]	0·068 and 0·049
,, ,, wireless mast [29]	0·049
Brick column [30]	0·148 and 0·06
,, chimney [30]	0·253 and 0·210

For frames and buildings ξE ranges from 0·26 to 0·788. For slender structures such as chimneys the damping may be appreciably less; it is

Figs. 4.



MODEL-FRAME: STEADY FORCED VIBRATION.

possible that in such cases the vibration is partly the result of the structur rocking as a whole on its foundation, and the nature of the damping ma consequently be different from that of elastic vibration. The constants fo

steel-framed buildings are much greater than that for mild steel, the increased damping being probably due to the concrete "clothing" of the frame.

As the motion varies in different earthquakes, and as it has been found that the general behaviour of a structure is similar for a simple-harmonic ground-motion and for an irregular vibration, a simple-harmonic ground-movement is assumed. The magnitude of the motion is defined by its maximum acceleration, a value of $0{\cdot}1g$ being adopted.

The maximum displacements of the floors relative to the base for steady forced vibration due to ground movements of the same maximum acceleration and of periods ranging from 2·0 seconds to 0·05 second are shown in *Figs.* 5, for the frame undamped, and with damping $\xi E = 0{\cdot}3$. Comparison of the two cases shows that damping has relatively little effect except for periods approximately equal to one of the natural periods. The effect is most marked in the neighbourhood of the period of the second mode, and it appears that large amplitudes of forced vibration are likely only for periods of the same order as the fundamental period.

The possibility of the periods of earthquake motion remaining constant for a sufficient time for steady conditions to obtain is remote, but two or three successive waves of approximately the same period are not unlikely. To find the effect of a limited number of similar waves, ground movements of 0·5-, 0·418-, and 0·35-second periods have been considered, and for each the motion of frame A during the first three cycles has been determined. Both sine ground-motion, beginning with zero acceleration and maximum velocity, and cosine motion, beginning with maximum acceleration and zero velocity, are considered. A maximum acceleration of $0{\cdot}1g$ is adopted in all cases. It is assumed that the frame is initially at rest, and that the floors are undisplaced relative to the base. The displacements of the base and of the floors relative to the base are shown in *Figs.* 6. Table V gives the maximum displacements of the floors and the ratios of these displacements for each cycle; the corresponding values for steady forced vibration and for a constant horizontal acceleration of $0{\cdot}1g$ are included for comparison. It will be seen that:

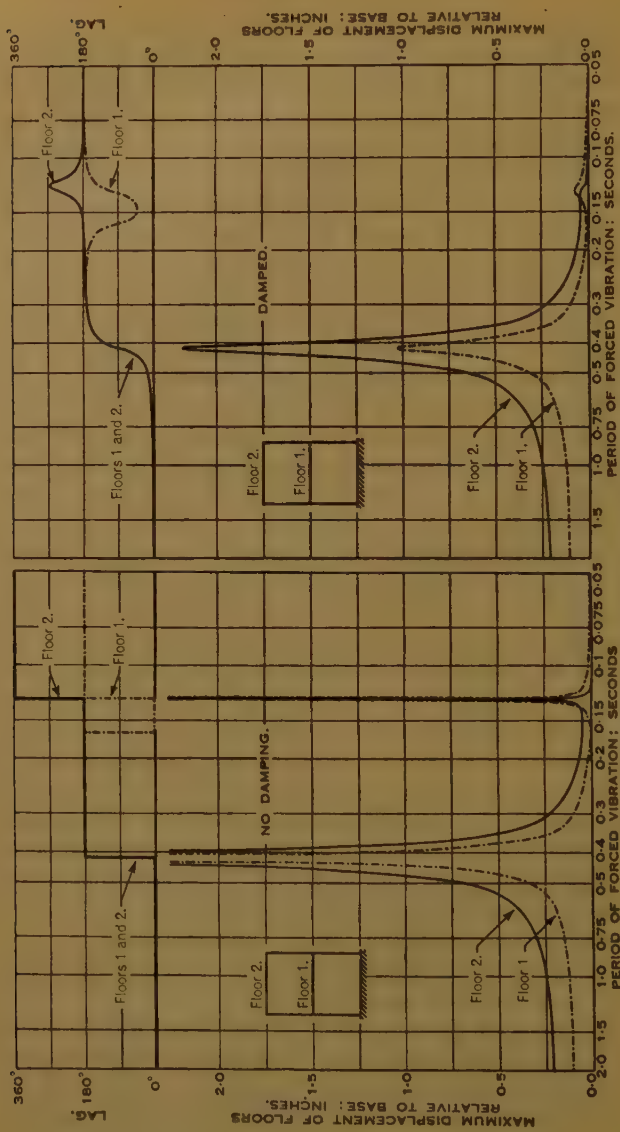
(1) The general behaviour of the frame is similar for both sine and cosine ground-movements.

(2) In all cases the amplitude of the second-mode component is negligibly small in comparison with those of the fundamental and forced-vibration components.

(3) The configuration of the frame differs little from that of the fundamental mode, the greatest difference between the ratios of maximum displacements and the ratio of amplitudes for the fundamental being only 4·2 per cent.

(4) As a result of beats set up between the fundamental and the forced-vibration components, the maximum displacements increase in each cycle. An exception occurs for cosine motion of 0·35-second period; here the greatest displacements

Figs. 5.

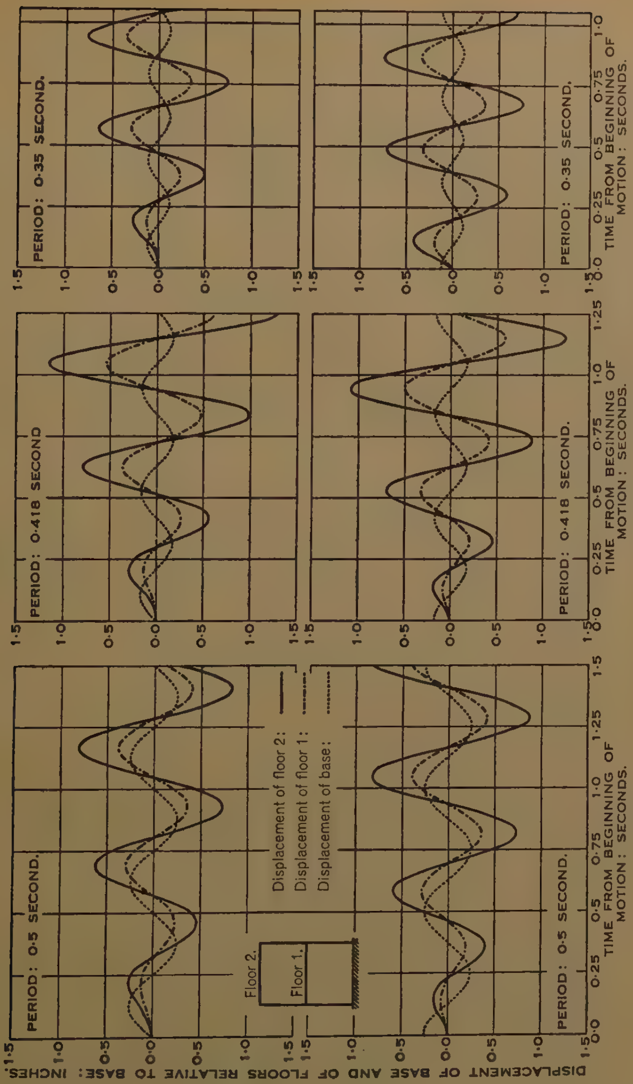


FRAME A: STEADY FORCED VIBRATION.

are reached in the second cycle, those in the third cycle being slightly smaller.

(5) In all cases the maximum displacements in the first cycle are approximately twice those due to a constant horizontal acceleration equal to the maximum acceleration of the ground movement.

Figs. 6.



FRAME A: THE FIRST THREE CYCLES OF FORCED VIBRATION.

(6) For periods of 0·5 and 0·35 second, the maximum displacements in the second and third cycles are greater than the amplitudes of steady forced vibration of these periods. At resonance the displacements increase less rapidly, those in the third cycle, though considerably greater than the values for the other periods, being little more than half the amplitudes of steady forced vibration. If, therefore, the ground motion consists

TABLE V.—MAXIMUM FLOOR-DISPLACEMENTS AND RATIOS OF DISPLACEMENTS FOR THE FIRST THREE CYCLES OF FORCED VIBRATION OF FRAME A.

		Period 0·5 second.			Period 0·418 second.			Period 0·35 second.		
		1st cycle.	2nd cycle.	3rd cycle.	1st cycle.	2nd cycle.	3rd cycle.	1st cycle.	2nd cycle.	3rd cycle.
Sine ground-movement.	Displacement of floor 1 : inch	0·23	0·35	0·40	0·26	0·46	0·60	0·21	0·30	0·36
	Displacement of floor 2 : inch	0·47	0·74	0·82	0·56	0·99	1·29	0·44	0·64	0·77
	Ratio	2·04	2·11	2·05	2·15	2·15	2·15	2·10	2·13	2·14
Cosine ground-movement.	Displacement of floor 1 : inch	0·18	0·36	0·42	0·22	0·42	0·58	0·27	0·35	0·34
	Displacement of floor 2 : inch	0·39	0·73	0·87	0·46	0·88	1·23	0·59	0·76	0·74
	Ratio	2·17	2·03	2·07	2·09	2·10	2·12	2·19	2·17	2·18
Steady forced vibration.	Displacement of floor 1 : inch		0·32			1·03			0·22	
	Displacement of floor 2 : inch		0·66			2·18			0·49	
	Ratio		2·07			2·12			2·22	
Constant horizontal acceleration.	Displacement of floor 1 : inch					0·11				
	Displacement of floor 2 : inch					0·21				
	Ratio					1·95				

of a few similar waves, the range of periods for which large displacements are possible is greater, and the displacements for periods close to that of the fundamental are less, than for steady forced vibration.

Large displacements of a frame are likely only for ground movements of approximately the same period as the fundamental. For such movements the configuration of the frame is very nearly the same as for the fundamental mode, and it is evident that a close approximation to the behaviour of the frame could be obtained by assuming it to be so constrained that the configuration was the same as that of the fundamental mode. The frame could then be treated as a system of one degree of freedom having a natural period equal to the fundamental period. It would be less accurate, but generally more convenient, to assume the configuration to be the same as that due to a constant horizontal acceleration. In Table VI the maximum displacements of frame A given by these assumptions for the first three cycles of a sine ground-movement of the same period as the fundamental are compared with those found by the general analysis. The first assumption gives a very close approximation; the second gives a close approximation for the upper floor, but overestimates the displacements of the lower floor by about 10 per cent.

TABLE VI.—MAXIMUM FLOOR DISPLACEMENTS (IN INCHES) OF FRAME A AT RESONANCE.

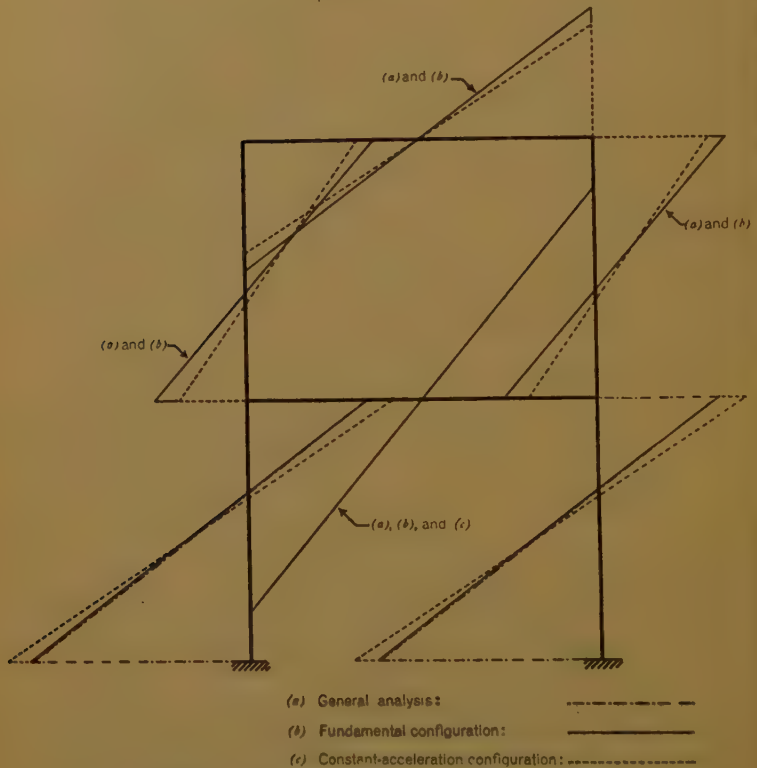
	General analysis.		Fundamental configuration.		Constant-acceleration configuration.	
	Floor 1.	Floor 2.	Floor 1.	Floor 2.	Floor 1.	Floor 2.
1st cycle .	0·26	0·56	0·26	0·57	0·29	0·56
2nd cycle .	0·46	0·99	0·46	0·99	0·50	0·97
3rd cycle .	0·60	1·29	0·61	1·30	0·65	1·28

The effect on the bending moments is shown in *Fig. 7*, which gives the bending-moment diagrams deduced from the maximum displacements in the third cycle for the three cases. The greatest error introduced by the assumption of fundamental configuration is only 1·5 per cent. When constant-acceleration configuration is assumed, the maximum moment in the upper stanchion-length is underestimated by 13 per cent., whilst that in the lower length is overestimated by 12 per cent.

To find the effect of the proportions of the members, two extreme cases have been considered. Both are two-storey frames generally similar to frame A, frame B having beams pinned to the stanchions, and frame C having rigid beams rigidly connected to the stanchions. The bending-moment diagrams for the third cycle of resonance, calculated on the assumptions of fundamental and constant-acceleration configurations

are shown in *Figs. 8*. Compared with the first assumption, the second underestimates the maximum moments in the upper stanchion-length by 17 per cent. for pinned, and by 15 per cent. for rigid, beams, and over-estimates those in the lower length by 8 per cent. and 5 per cent. respectively. The corresponding bending-moment diagrams for frames D and E, three-storey frames similar to B and C respectively, are given in *Figs. 9.*

Fig. 7.



FRAME A: BENDING MOMENTS AT RESONANCE.

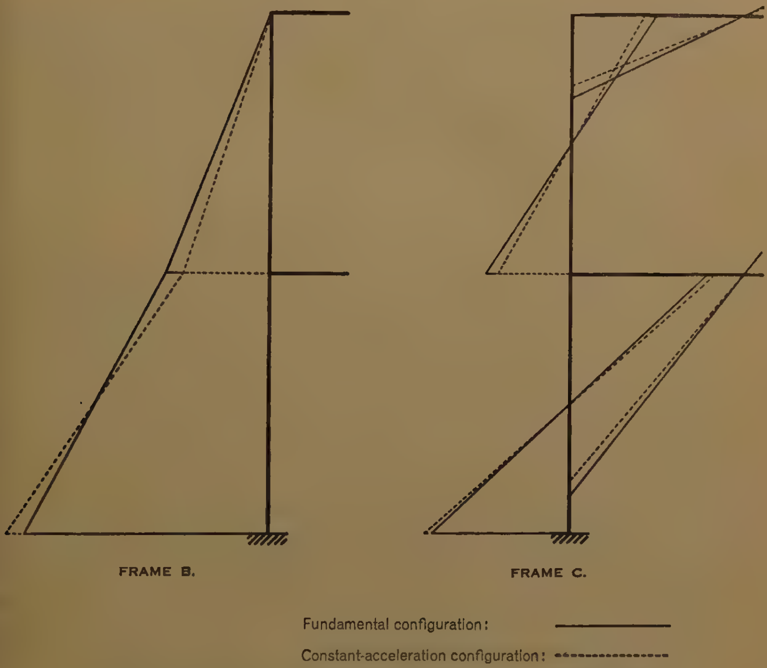
In comparison with the assumption of fundamental configuration, that of constant-acceleration configuration underestimates the maximum moments in the topmost stanchion-length by 22 per cent. for pinned, and by 18 per cent. for rigid, beams; those in the bottom lengths are overestimated by 10 per cent. in both cases.

The influence of the damping is shown in *Fig. 10*, which gives the maximum displacements of the upper floor of frame A in the first three cycles of resonance with the fundamental, for values of ξE from 0·01 to 1·0

In the first cycle the effect of variation in damping is comparatively small; this effect is more marked in subsequent cycles, but it is evident that reasonably accurate results can be obtained without a very precise knowledge of the damping constant.

From the behaviour of the frames considered, it appears that, for ground movements of about the same period as the fundamental, the stresses can be estimated without serious error by assuming the con-

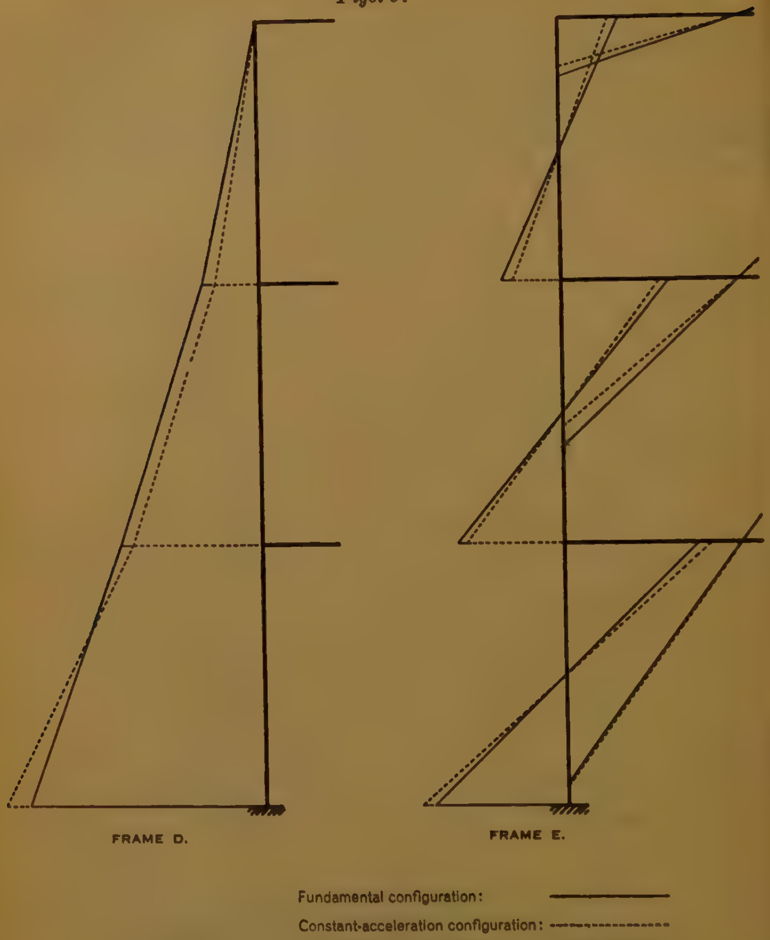
Figs. 8.



FRAMES B AND C: BENDING MOMENTS AT RESONANCE.

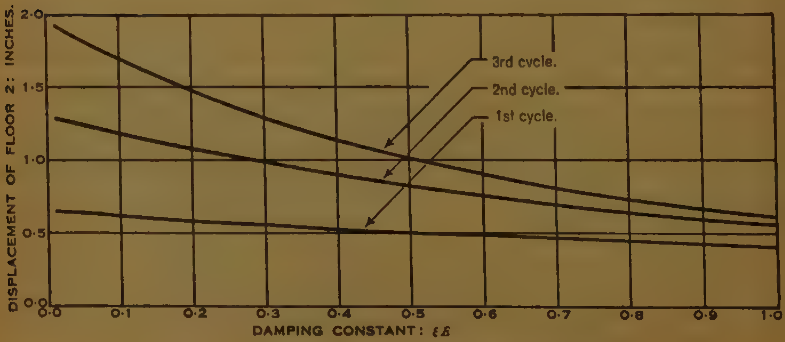
figuration of the frame to be that due to a constant horizontal acceleration; these stresses may be several times those due to a constant acceleration equal to the maximum acceleration of the ground motion. The assumption usually made in earthquake-resistant design, that earthquake motion can be represented by a constant horizontal acceleration, therefore appears to give a reasonably accurate picture of the nature of the stress-distribution at resonance. The magnitudes of the acceleration used in design are, however, quite arbitrary.

Figs. 9.



FRAMES D AND E: BENDING MOMENTS AT RESONANCE.

Fig. 10.



FRAME A: EFFECT OF DAMPING AT RESONANCE.

Summary and Conclusions.

The ground motion during an earthquake is an irregular vibration. Although the vertical movement may be large near the epicentre, in most of the area affected the motion is mainly horizontal, and the destructive effect appears to be due chiefly to the horizontal movement. The periods of this movement often vary continuously; a long series of similar waves is unlikely, but two or three successive waves may have approximately the same period. The periods of the horizontal waves may vary from less than 0·1 second to as much as 5 seconds, this range including the natural periods of all normal buildings. Long-continued resonance in a building due to earthquake motion is improbable, but resonance may occur for a few cycles. This possibility should be considered in earthquake-resistant design. Since the ground movement varies in different earthquakes, some conventional motion must be assumed as a basis for design. Since long-continued resonance is unlikely, and as the general behaviour of a structure appears to be similar for a simple-harmonic, and for an irregular, ground-motion, it is suggested that a limited number of simple-harmonic waves, say two or three, would form a suitable design basis.

The determination of the stresses in a building frame due to a periodic ground-movement is a dynamic problem, the solution of which requires a knowledge of the nature of the structure considered as a vibrating system. An exact analysis of the lateral vibration of a building frame would be too laborious to be practicable. Simplifying assumptions must be made, but if these are too sweeping the analysis may be simplified at the expense of disguising the true behaviour of the frame. A general method of analysis is given, which may be applied to any frame, and in which all the factors likely to affect its behaviour appreciably can be taken into account. To check the validity of this analysis, an experimental investigation of the lateral vibration of a model building-frame was carried out. Satisfactory agreement was obtained between the observed and the calculated values, the differences being generally less than 5 per cent.

This analysis was used in an investigation of the behaviour of building frames subjected to periodic ground-movements. It appears that if the period of the movement is equal to that of one of the higher normal modes the deflexions will, owing to the effect of damping, be relatively small. Large deflexions and stresses will occur only when the period of the ground motion is of the same order as the fundamental period. The free vibrations set up make the range of periods giving large deflexions greater than for steady forced vibration, the maximum deflexions and stresses occuring when the period of the ground movement is equal to the fundamental period of the structure. Two or three waves of this period cause stresses which, though considerably less than those due to steady forced vibration, are much greater than those given by a constant acceleration equal to the maximum acceleration of the ground motion. The greater the damping

of the frame the smaller are the stresses developed, but if the ground motion consists of only a few waves, appreciable changes in damping cause relatively small changes in stress. For periods of the same order as the fundamental period, the nature of the stress-distribution does not differ materially from that due to a constant horizontal acceleration. For the frames considered here the stresses at resonance can be estimated to within about 20 per cent. by assuming the stress-distribution to be of this form; the maximum stresses in the lowest stanchion-lengths are over-estimated, whilst those in the topmost lengths are underestimated.

In the usual method of earthquake-resistant design earthquake motion is represented by a constant horizontal acceleration. It has been generally considered that, although this assumption is justifiable for ground motions of periods greater than the natural periods of a building, where resonance is possible it has little beyond its simplicity and convenience to recommend it. The Author's investigations, however, indicate that even in the most severe case, that of resonance with the fundamental, the nature of the stress-distribution in a building frame is not seriously different from that given by this assumption. The magnitudes of the stresses given by the horizontal acceleration generally assumed, $0{\cdot}1g$, may be seriously in error. Considerably greater accelerations have been recorded in severe earthquakes, and two or three similar waves can cause stresses several times greater than those given by a constant acceleration equal to the maximum acceleration of the motion. The accelerations used in design should depend on the damping of the frame as well as on the possible intensity of earthquake motion. The determination of suitable values is beyond the scope of this Paper; it could, perhaps, best be done by studying the behaviour of models on a shaking-table capable of reproducing the irregular movements of an earthquake.

The conclusions given have been drawn from the study of a limited number of two- and three-storey frames. It is probable that they apply generally to low buildings; the behaviour of multi-storey frames may be somewhat different. Mathematical analysis of the vibration of such structures would be too laborious to be practicable, but the consistent results obtained in the experimental work, and their close agreement with the calculated values, show that model-analysis forms a reliable and accurate means of investigating the vibration of structures.

The Paper is accompanied by eight sheets of drawings and by two photographs, from which the half-tone Plates and the Figures in the text have been prepared, and by the following Appendix.

APPENDIX.

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Paper No. 5255.

"Some Corrosion Tests in a Railway Tunnel."

By Sydney Charles Britton, M.A.

(*Ordered by the Council to be published with written discussion.*)[1]

TABLE OF CONTENTS.

Introduction.

Serious difficulties in constructing ventilating equipment to deal with the soot and gaseous products resulting from coal combustion are created by corrosion of the materials of construction. This has been emphasized by unfortunate experiences at the Union railway station, Chicago,[2] where hanger rods of 14-per-cent. chromium steel, $\frac{3}{4}$ inch thick, in the ventilating plant, were completely severed by corrosion within 3 years. Therefore, when the London Midland and Scottish Railway Company was considering new building which involved the provision of equipment for the removal of exhaust-gases from steam locomotives, a series of tests was carried out. Decisive results were obtained, and it is felt that these may be useful in other connexions than the specific purpose for which the test was made.

Method of Test.

It was found that a sufficiently close parallel to the expected conditions could be produced in a ventilating shaft of the St. Pancras tunnel. This tunnel is 1,396 yards in length, and the shaft, near its middle, is fitted

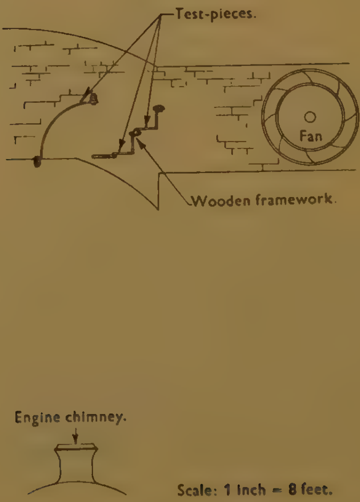
[1] Correspondence on this Paper can be accepted until the 15th August, 1941, and will be published in the Institution Journal for October, 1941.—Sec. Inst. C.E.

[2] "Building above Steam Operation presents Problems." *Railway Age*, vol. 105 (1938), p. 370.

with an electrically-driven fan which expels smoke through a side outlet at the top of the tunnel.

In the proposed plant, corrosion was most feared in regard to parts receiving direct blast from locomotive chimneys and parts on which accumulations of soot could lodge. Two types of test-plate were therefore employed. For one type, seventeen curved plates, each 1 foot broad and forming a quadrant of a cylinder of 2 feet radius, were arranged above the line of passage of locomotive chimneys. The alternative form of test-piece was a 2-foot by 1-foot plate bent to form two 1-foot squares, one horizontal and the other vertical; and two rows of these were exposed, the general arrangement being as shown in *Fig. 1*. The height of the bottom of the baffle-plates above the track was 24 feet.

Fig. 1.



The specimens were fixed in position in December 1936 and January 1937. Occasional inspections were made on the site, but these did not enable a complete assessment of their condition to be made, as, although it was considered permissible to brush off some soot, care was taken not to remove corrosion products or protective coatings, which often concealed the true condition of the metal. All of the specimens were removed from the tunnel, cleaned, and examined after exposure for 3½ years.

Some measurements of atmospheric pollution made at the position occupied by the angle test-pieces yielded the following results :—

1. The sulphur dioxide concentration in the air ranged from 2 to 9 parts per million according to the amount of traffic using the tunnel. The highest values were obtained during the periods 8–10 a.m. and 4.30-

6.30 p.m., when the traffic was heaviest. (In the open air the sulphur dioxide content usually varies from 0·01 to 0·4 part per million, depending upon the locality and the season.)

2. The relative humidity of the atmosphere was 100 per cent. for at least 10 hours each day, the value during the remainder of the time being dependent upon that of the outside air. At no time did surfaces in the positions used for the exposure test become free from visible moisture.

3. The deposit remaining on a horizontal glass surface averaged 1·40 milligram per square centimetre (0·046 ounce per square foot) per day; 75 per cent. of this was water. A typical deposit remaining on a glass surface of 100 square centimetres after exposure for 14 days contained the following matter, expressed in milligrams: water, 1,590; tarry matter, 217; other carbonaceous material, 154; insoluble mineral matter (ash), 100; soluble sulphates (expressed as sulphuric anhydride), 19; soluble chlorides (expressed as chlorine), 9; soluble iron (expressed as ferric oxide), 14.

Materials Exposed.

The materials exposed were all such as seemed likely to have useful corrosion-resistance. They may be divided roughly into the following five groups:—

(1) mild steel protected by various coatings;
(2) stainless steels;
(3) non-ferrous metals and alloys;
(4) cast irons;
(5) non-metallic materials.

Some bare mild-steel plates were also exposed in several positions as a test of the uniformity of conditions over the whole of the exposure. Most of the specimens were in the form of hot-rolled sheet of 14 S.W.G. (0·080 inch thick), with surfaces in the bright condition; but the cast-iron plates, which were flat, were 0·3 inch thick and their surface was as cast.

Details of the materials tested and the general results are given in Table I, facing page 72, *post*. Perforation is defined as the penetration of corrosive action completely through the sheet, whether by formation of an actual hole or by the development of any form of embrittlement due to corrosion.

The behaviour of uncoated steel plates indicated no serious variation in the effects of corrosion at various positions of the exposure-rack. Differences between horizontal and vertical surfaces were small and were never sufficient to cause any doubt as to the order of merit of materials. With the exception of painted and metal-sprayed angle test-pieces, no side differences were found between the two sides of the test-plates.

Results of Tests.

Comments on Individual Classes of Material.

(*a*) *Non-metallic materials.*—The moulded bakelite-fabric pulley (*Fig. 2*) was the only material to appear almost unchanged at the end of the test. Other bakelite pulleys, machined from laminated sheet, have also yielded good results in service in other tunnels. The tensile strength of the pulley-material was given by its makers as 6,000–7,000 lb. per square inch, with an ultimate crushing stress of 30,000–35,000 lb. per square inch. The low specific gravity (1·37) is an advantage.

It is not considered that the period of exposure was sufficiently long to enable the ultimate fate of the concrete test-pieces to be inferred.

(*b*) *Protective coatings.*—The acid conditions were not favourable to any chemical protection by paint materials, and although an aluminium coating afforded temporary electro-chemical protection, it was itself consumed rapidly. Apparently success with protective coatings can be hoped for only from imperviousness to corrosive influences: thus, only thick coatings such as rubber, impregnated fabric, or reinforced bitumen gave promise of more than 2 years' protection; but such thick coatings had the disadvantage that corrosion could proceed beneath their surface unnoticed. Moreover, their successful application to curves of small radius is difficult, and breakdown of all the thick coatings except rubber occurred at the edges of the test-pieces and, to a smaller extent, in the angle.

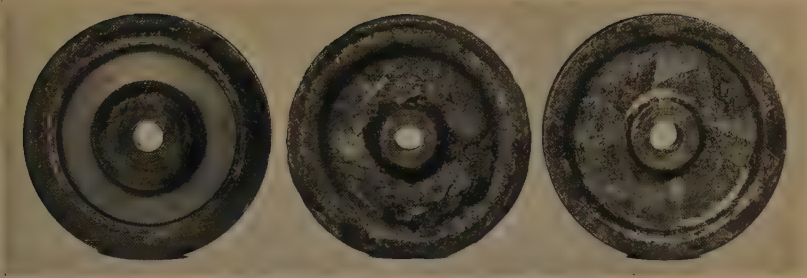
The sides of the painted or metal-sprayed angle test-pieces facing the tunnel were attacked much more severely than the reverse sides, probably because they were more continuously wet. The penetration of corrosive influences through a protective coating is likely to be less destructive when occasional drying permits pores to become blocked by solid corrosion-products. *Figs. 3, 4*, and *5* respectively illustrate test-pieces of bare mild steel, painted mild steel (specimen No. 12A), and rubber-coated mild steel (specimen No. 5A), after exposure.

(*c*) *Stainless steels.*—The rapid pitting of the stainless steels was not surprising in view of the experience at Chicago referred to in the introduction. The austenitic material behaved little better than the straight chromium variety: it had fewer perforations at the end of the test, but tensile tests made on 1-inch-wide strips of the corroded material showed that its elongation had decreased to 3 per cent. on 2 inches. It is noteworthy that perforation of the plates was more rapid than that of well-painted mild steel.

It has been shown that austenitic stainless steels suffer little or no corrosion in the condensed products of combustion of coal-gas[1]: probably

[1] Report of the Gas Conditioning Committee of the American Gas Association; Corrosion of Metals and Alloys by Flue Gases. Appendix I. American Gas Association Proceedings, 1939, p. 542.

Fig. 2.

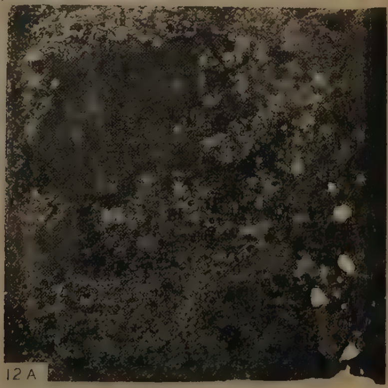


PULLEYS: LAMINATED BAKELITE SHEET, GALVANIZED IRON, AND MOULDED BAKELITE-FABRIC.

Fig. 3.

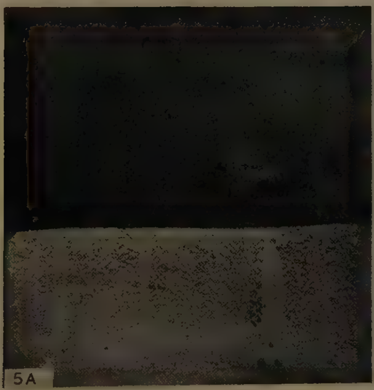
BARE MILD STEEL.

Fig. 4.



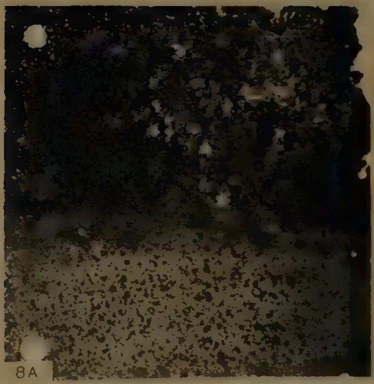
MILD STEEL, PAINTED.

Fig. 5.



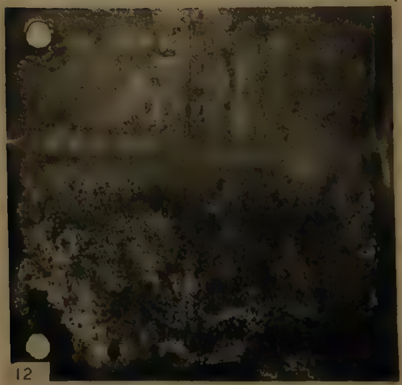
RUBBER-COATED MILD STEEL.
COATING REMOVED FROM LOWER HALF.

Fig. 6.



STAINLESS-STEEL, LOWER HALF CLEANED.

Fig. 7.



COPPER, UPPER HALF CLEANED.

in those tests no solid deposit fell on the metal. Contact with solid material has often been found to produce local breakdown of passivity in stainless steels, probably because it prevents free access of oxygen to the metal surface. In the St. Pancras tunnel tests, the soot would doubtless act in this manner, and the presence of chlorides in the deposit would assist the process. The severely-localized form of corrosion, resulting in isolated pits, is frequently encountered in circumstances in which complete passivity just breaks down. Apparently only the weakest spots in the protective surface-film of oxide yield at first, and the probability of corrosion commencing elsewhere in the neighbourhood of any one of them is decreased by the surrounding metal becoming the positive member of a corrosion-cell. Corrosion thus becomes concentrated on the initial weak points, and the large cathode-surface provided by the remainder of the surface favours rapid penetration if the surface is always wet.

The more continuous form of corrosion produced along the softened zone in the welded chromium steel (*Fig. 6*) was due to the precipitation of carbides in the metal by the welding heat. This, by reducing the amount of chromium effective for producing passivity, allowed corrosion to begin at numerous points.

(*d*) *Copper and its alloys.*—Copper (*Fig. 7*) and copper alloys became covered with a layer of green corrosion-products consisting of mixed basic sulphates and chlorides, and it is believed that these layers which, except on aluminium-bronze and, to some extent, on cupro-nickel, were compact and adherent, protected the metal very considerably from further corrosion. No pits formed on copper or its alloys, but there was slight intercrystalline penetration of corrosion in the aluminium-bronze angle-plate and in the two "Everdur" specimens. This did not seriously affect the strength of the materials. In order to test this, tensile test-strips with a width of 1 inch on the parallel portion and a gauge-length of 2 inches were cut from each of the angle test-plates. Specimens of unexposed materials were tested in similar form. Unfortunately, owing to an error in supply, the samples of original material were not cut from the same sheets as the exposed material, although they were of similar analysis and treatment, and the new copper and cupro-nickel test-pieces were slightly harder than the exposed samples. The test-results given in Table II (p. 70), show how small is the change in these materials.

The corrosion of the aluminium-bronze deflector-plate (specimen No. 2B) was surprisingly rapid in comparison with that of the angle-plate (specimen No. 11), which contained only 0·5 per cent. less aluminium, but had a different microstructure. Corrosion resulted from electro-chemical action between the two phases of the alloys. In the deflector-plate the second phase was a continuous network which had allowed corrosion to penetrate along it without interruption, whereas the discontinuous second phase in the angle-plate had not permitted this. The corroded deflector-

plate did not appear much altered on the surface, but it cracked on the slightest degree of bending.

(*f*) *Cast Iron*.—Initial variations in thickness of the cast-iron plates rendered difficult determination of the loss of thickness of metal and, hence, comparison with steel. On the plain cast iron the thickness of the graphitized layer alone was nearly equal to the thickness lost from mild steel, and therefore the rate of penetration of corrosion into the iron was at least as fast as into the steel. For the most part the corroded iron does remain together as a solid mass, even if it has little strength, and this is often advantageous. The better behaviour of the special cast iron (specimen No. 5B) with finely-dispersed graphite flakes was not unexpected,

TABLE II.

Material.	Loss of thickness of sheet: inch.	Final mechanical properties.		Original mechanical properties.	
		Breaking load of 1-inch strip: tons.	Elongation: percentage on 2 inches.	Breaking load of 1-inch strip: tons.	Elongation: percentage on 2 inches.
Copper . .	0·005–0·007	1·056	55	1·234*	57*
Everdur . .	0·005–0·007	1·773	75	1·938	74
Cupro-nickel .	0·008–0·010	1·638	45	1·938*	27*
Aluminium-bronze .	0·007–0·012	2·635	41	2·992	52

* Determined on material slightly harder than the exposed samples.

as it has been frequently noticed, particularly in acid conditions, that corrosion can penetrate into cast iron along coarse flakes.

Like the stainless steels, the austenitic cast iron suffered corrosion over restricted areas, but this was confined to quite shallow local graphitization.

General Comments.—The foregoing comments give some indications of how far the results obtained are generally applicable. For instance, it appears that painting and metal spraying would have given relatively better performances if conditions had not been so continuously wet, and that stainless steels might have justified their name if there had been no soot. Abrasive action, which prevented the formation of layers of basic salts on copper and its alloys, would have accelerated their disappearance. The only variation in conditions included in the test (the two types of test-plate) did not produce appreciable results. There was some action: stainless steel deflector-plates were perforated less rapidly than were the more sooty angle-plates; but mild steel, either bare or coated, was more seriously attacked in the form of deflector-plates.

The results are probably applicable to a fairly wide range of conditions which involve soot, moisture, and gaseous products of combustion. They

are not all necessarily reliable for circumstances in which the products of combustion are not diluted with air and some moisture, or in which there is considerable mechanical abrasion of the metal surfaces.

Summary.

Non-ferrous metals and alloys, mild steel protected by paints, by metal coats, or by thick wrappings, cast iron, stainless steels, and a few non-metallic materials were exposed in the ventilating-shaft of a steam-operated railway-tunnel for periods ranging up to 3½ years.

A moulded bakelite-fabric pulley was the only specimen to remain substantially unchanged, whilst copper, although superficially corroded, became covered with a protective coating of corrosion-product, and proved to be the best metallic material. Other copper alloys, "Everdur" and cupro-nickel, which have better mechanical qualities than copper, also did well, but are not expected to be quite so durable. Two specimens of aluminium-bronze differed in behaviour: one, with a well marked two-phase microstructure, was seriously embrittled, whilst the other, with only isolated fragments of a second phase, behaved like the other copper alloys.

Aluminium and stainless steel suffered severe local attack, and 14-S.W.G. sheets were perforated at many points within 3 years.

Mild steel in 14-S.W.G. sheets was entirely destroyed within 3 years, but almost complete protection was afforded to it by a thick rubber coating. Other thick coatings, such as bitumen reinforced by asbestos and cotton lint impregnated with petroleum jelly, also gave fair protection. Metal coatings of aluminium and lead sprayed on to mild steel, and other aluminium coatings applied by cementation processes, failed quickly. Well-chosen paint coatings had as long a life as these metal coats, but allowed rusting to commence after, at most, a year.

A plain cast iron suffered considerable "graphitization", that is, conversion of the metal into a mixture of rust, graphite, and residual iron. A special cast iron with finely-dispersed graphite flakes was less badly attacked, and a highly-alloyed austenitic cast iron suffered only shallow localized graphitization.

Concrete suffered only superficial softening, and the reinforcement, 1½ inch beneath the surface, was unaffected after 3 years.

Acknowledgements.

Thanks are due to Mr. W. K. Wallace, M. Inst. C.E., Chief Engineer of the London Midland and Scottish Railway, and to his staff for ready co-operation in the tests described; to Mr. F. Fancutt, F.I.C., for arranging for the painting of test-panels, and to Mr. A. W. Hewer, who made many analyses of the sooty deposits and of the atmosphere. Brigadier-General

Sir Harold Hartley, C.B.E., M.C., F.R.S., Vice-President of the Railway and Director of Research, kindly accorded permission for publication of the results.

The Paper is accompanied by six photographs and one drawing, from which the half-tone page-plate and the Figure in the text have been prepared.

[The following Bulletin is supplementary to the Note by Professor J. F. Baker, "The Resistance to Collapse of Structures under Air Attack," printed at pp. 481–484 of the October 1940 number of the Journal. That Note was written in November 1939, before there had been any experience of bombing in this country. The general principles set out therein have stood the test of actual bombing experience. The Research and Experiments Department have now, however, been able to produce the following more detailed principles of design based on lessons learned from actual air raid damage.]

"Single Storey Wartime Factory Design." *

Introduction.

A MAIN object of air attack is to paralyse production. By dropping high explosive and incendiary bombs the enemy seeks to demolish or burn out factory buildings, ruin the plant, and kill, maim, or at least demoralize, the workers. Fortunately for the defence, wartime designers can do much to make factories highly resistant to collapse and difficult to fire, damage can be localized, and the steadiness of the workers reinforced by giving them cover at hand. The intelligent development of the design methods advocated is regarded as an important counter in maintaining production despite air attack.

Serious as has been the structural damage caused by high explosive bombs to certain factories, the effects of high explosives are not so deadly as the effects of fire. Up to the present far more steelwork has been destroyed by fire than by high explosives.

The simplest way of minimizing fire damage is to limit the combustible materials in the factory to the essential minimum. This applies also to the roof, where timber purlins, or any form of slates or tiles on boarding, should on no account be used.

Correct planning of a factory can play at least as big a part in minimizing bomb damage as correct structural design.

The tendency towards very large buildings, which is so marked to-day, should be reversed. In the event of a direct hit by a large bomb, all the glass and roofing material in the building, almost irrespective of its size, will be destroyed. Even in a small building, the explosion will to some extent be confined by the walls and roof, and adjacent buildings will be relatively undamaged.

* Issued by the Ministry of Home Security, Research and Experiments Department as Bulletin C 12, and reprinted in the Journal by permission of the Ministry.

It therefore follows that it is preferable to sub-divide a factory into as many units as possible, rather than to concentrate everything into one large building. This has the additional advantage of minimizing the area likely to be destroyed by fire. Moreover, it may be possible to arrange production in several parallel lines, so that if a link in one line is destroyed it can be by-passed and production need not be seriously interfered with.

Principles of Design.

By far the most common type of factory for wartime production is the single-storey building, and this Bulletin is concerned with the principles of design applicable to this type.

The first principle is that all loads should be carried by a framework of steel or reinforced concrete. Load-bearing walls are dangerous because an explosion can demolish instantly long lengths of walling, bringing down with them all that rests on them.

So far little experience of the behaviour of reinforced-concrete single-storey frames has been obtained. It is known that a reinforced-concrete member is more severely damaged by a direct hit than a comparable steel member. It may therefore be impossible to eliminate collapse entirely in reinforced-concrete framed shed buildings. The evidence so far available suggests, however, that where reinforced concrete is used the most satisfactory way of minimizing damage is to take advantage of construction joints to provide complete breaks in the structure at frequent intervals.

In the meantime, this Bulletin is addressed primarily to the problems of design in steel.

Steel Framing.

The second principle is that the steel frame should resist collapse notwithstanding the sudden removal of any one main member. This is not so rigorous as it sounds. Near the explosion, the load is generally relieved by the roof covering being blown away, and there have been a number of cases where direct hits have severed either the rafter or the main tie of a steel roof truss without even producing a measurable sag.

The chief risk to roof steelwork arises from the violent displacement of a stanchion foundation and the consequent shearing of the stanchion cap connexion leading to collapse of roof trusses. This risk is eliminated if two simple precautions are taken. The cap connexion of the stanchion to the roof member should be made stronger than is usual, in order that it shall not be sheared off even if the stanchion base is shifted 4 or 5 inches by a near miss. This precaution is particularly necessary in the case of trusses or beams framing into external stanchions. In addition to the effects of ground movement, such stanchions are liable to be subjected to a considerable horizontal blast pressure applied to them by whatever

vall construction is adopted. Provided their cap connexions are adequate, iowever, the worst effect of this blast will be to bow out the stanchions vithout causing any major damage, or collapse. In addition, the roof irder or valley beam should be spliced so as to be continuous. This will nsure that, even if a stanchion is destroyed, the valley beam is adequate o carry the dead load only of the roof (without the sheeting) over two ays. These precautions will not serve if two adjacent stanchions are lestroyed, and a stanchion spacing of at least 30 feet each way is desirable o prevent this.

An explosion inside a factory forces the roof upwards and the steel-vork should be designed to resist this by using angles rather than flats for ill tension members and by attention to the roof covering, as suggested n p. 77, *post*.

Generally speaking, the experience of recent air raids has indicated hat the roof types recommended in Wartime Building Bulletins Nos. 1[1] nd 4[2] are the best possible from the point of view of resistance to air ttack, provided that they are fully steel-framed. The following points hould, however, be borne in mind in relation to the individual types; the nodifications suggested below have been made to the type designs, and re given in Wartime Building Bulletin No. 10[3].

Type B. Sheeted Roof consisting of symmetrical roof trusses carried on alley beams. Experience shows that it is only by the destruction of a tanchion that any collapse of this type of roof can be produced. This anger can be eliminated if the valley beam splices are designed to develop uch a strength that the dead load only of the roof (without the sheeting) an be carried over two bays.

Type C. Sheeted Roof consisting of symmetrical "umbrella" trusses ıntilevering on either side of apex lattice girders. This type was included ı the Bulletin in preference to the more usual north light type, solely ith a view to its inherent resistance to collapse. If full advantage is to e taken of this, minor amendment to the original design is necessary. he lattice girders should be strengthened to enable them to act as con-nuous girders.

Even if the precautions outlined above are taken, there is the possi-ility that fire or other unforeseen occurrences will bring down a portion f the steelwork. In this event it is essential that the collapse should be calized and should have no tendency to spread and involve the adjoining ndamaged steelwork. The only form of spreading collapse to which the bove types are liable occurs with Type B, and may happen if a number of ljacent trusses in the same bay collapse. The purlins may then apply

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[1] Economical Type Designs in Structural Steelwork for Single-Storey Factories. .M. Stationery Office, London, 1940.

[2] Supplementary Type Designs in Structural Steelwork for Single-Storey Factories. .M. Stationery Office, London, 1940.

[3] General Principles of Wartime Building. H.M. Stationery Office, London, 1940.

an excessive horizontal pull to the neighbouring trusses, pulling them over and producing a spreading collapse. This danger can be guarded against by providing at intervals in each bay wind-bracing capable of sustaining any pull which the purlins can transmit.

Walls.

The external walls of a wartime factory should be regarded as simply protective screens against weather and bomb fragments. The danger attendant on load-bearing walls has been mentioned already. Hence the external walls should consist of panels of the materials and thicknesses specified in the Revised Code[1]. Such laterally protective panels should not be built into the webs of steel stanchions, but should be butt-jointed against the concrete or brick with which the stanchions should be encased. If the height of the panels is 6 or 7 feet above the factory floor-level, this will suffice for lateral protection. In the space between the top of the panels and the eaves of the roof, sheeting on steel framing should be fitted. Panels and sheeting should be so designed that blast damage shall not be transmitted by them to the framing. To ensure that the sheeting shall blow in harmlessly, it should be of asbestos-cement or other brittle material, with anti-scatter protection by means of wire or sisal netting, which may be of large mesh, securely fixed to the steel framing behind the sheeting. The use of corrugated steel sheeting is not recommended for walls, as although it will blow out harmlessly from a hit inside the building, it is liable to cause considerable buckling of the steelwork under the effects of a near miss outside the building.

If natural illumination is regarded as essential, the space above the dwarf walls may be glazed, preferably with a translucent flexible glass substitute[2]. If glass is used it should be covered internally with wire netting not exceeding ½-inch mesh, securely fixed to the structure.

In non-essential buildings, if load-bearing brick walls or piers are used to economize steel, similar principles of construction should be adopted. Load-bearing brick piers separated by panels with straight joints between panels and piers should be used in preference to continuous brick load-bearing walls. The height of the panels and the space between top of panel and eaves should follow the principles advocated above for framed structures. The panels should be of the materials and thicknesses specified in the Revised Code.

The use of lightweight internal partitions to subdivide a factory should be avoided. Such partitions are particularly liable to blast damage, and if glazed or sheeted with a brittle material they are a serious source of danger to personnel.

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[1] Air Raid Shelters for Persons working in Factories, Mines, and Commercial Buildings. Revised Code. H.M. Stationery Office, London, 1940.

[2] "Flexible Substitutes for Glass," Ministry of Home Security, Research and Experiments Department. Bulletin C. 10 (1940).

Substantial internal partitions, however, can be designed to afford a onsiderable measure of protection. If they are built the full height of he shop they will provide useful fire stops, and may limit blast damage to he roof. They should be framed in steel or reinforced concrete ndependent of the main structure.

Roof Covering.

ı) *Protected Roofs* (Type A of Wartime Building Bulletin No. 1. Flat roof incorporating monitor lights and giving overhead protection by a 4-inch reinforced-concrete slab).

The little evidence so far available on the behaviour of this type of oof under the effects of direct hits and near misses indicates that it should fford considerable protection to the factory from debris thrown up from omb craters. It may even give some protection to plant against the ffects of those light bombs which, being instantaneously fused, explode hen they strike the roof. Such a bomb would merely blow a hole about feet square in the roof, with relatively little damage to the interior of the ıctory.

The effect of a large bomb exploding inside a factory is, however, kely to be much more serious. The reinforced-concrete roof slabs will ndoubtedly be lifted over a fairly wide area. It is possible that they may lso be displaced slightly and fall back into the shop instead of on to the ıpporting steelwork. Should this occur the roof slabs would do even ıore damage than the bomb, and this eventuality must be guarded against ; all costs. The best safeguard would be to anchor the slabs to the steel amework. Such anchorage need not be of any great strength, but it ıould be designed to withstand an uplift pressure on the roof of at least)0 lb. per square foot. Alternatively the slabs may be linked together. saving of steel could be effected if the slabs were designed to be con- nuous, such continuity being provided by additional top reinforcement aced in position and grouted in after the slabs are erected.

) *Sheeted Roofs* (Types B and C of Wartime Building Bulletin No. 1).

Roofs are less subject to external blast from a near miss than are walls. ıe objection to the use of corrugated steel for walls does not, therefore, pply to sheeted roofs, for which it is the ideal covering. The area of eeting likely to be destroyed by a direct hit is about fifteen times as eat for asbestos cement as for corrugated iron. The spacing of hook lts usual with corrugated steel sheeting, about one to every 6 to 8 square et of roof, is sound. With this spacing, the hook bolts being slightly eaker than the purlins, the sheeting will be blown off without damaging e purlins. With a closer spacing of hook bolts, the purlins would be ble to extensive damage, and with a wider spacing an unnecessarily

large area of sheeting be stripped. Proprietary forms of sheeting consisting of flat or corrugated steel sheets coated with a waterproofing compound behave in a similar manner to corrugated steel. The resistance of asbestos cement sheeting to blast can be considerably increased by reinforcing it, preferably with light-gauge sheet steel. Such sheeting reinforced with fabric tape has a considerably greater resistance to impact loads than unreinforced sheeting. No evidence is, however, so far available as to the areas of reinforced asbestos cement sheeting likely to be damaged by the blast from a direct hit.

Insulating board lining under sheeted roofs should on no account be used. Under a direct hit such a lining does not save the roof sheeting and causes extensive damage to the roof steelwork. Unlined roof sheeting fixed in the usual way is capable of being blown off without damage to the steelwork. The presence of the lining, however, results in an excessive uplift being applied to the steelwork and may cause very extensive damage to it.

Roof Glazing.

A main cause of delay in returning to full production in bombed factories has been extensive damage to roof glazing, which has all to be repaired before night work can be resumed. For this reason, it is most desirable that roof glazing should be entirely eliminated from new factories, work being carried out solely by artificial light.

For ease of conversion in peacetime it may be desirable to make arrangements for future glazing to be inserted. This can be done by designing a normally glazed roof and replacing the glass by flat sheets of weather-proof material. Such materials should be similar in strength and elasticity to the sheeting used on the roof.

If it is considered essential to maintain natural illumination the minimum amount of glass, or preferably of flexible glass substitute, to give the required lighting should be used.

Provided that wired glass is used and is supported by battens fixed between the glazing bars, it is possible that it may remain weatherproof under fairly severe blast. Even with these precautions, however, the danger of falling glass is not eliminated, and wire netting, which may be of a fairly coarse mesh, should be securely fixed beneath the glass. If unwired glass is used, wire netting of not more than ½-inch mesh should be provided underneath it.

Services.

Gas, water, and electricity services are particularly liable to bomb damage. In many cases cast-iron and other buried pipes have been fractured by ground movement at a distance from the bomb explosion.

Sometimes the fracture has not been discovered until the plant has been started up again, and a further delay in production has occurred until the services have been repaired.

In new factories, this danger can be largely eliminated by isolating the service pipes from the effects of ground movement. The principle should be to provide an air space between the pipe and the surrounding ground. This can be done in several ways. The pipes can be laid in ducts, or in certain cases guard trenches can be provided on each side of important service pipes.

Additional Measures for the Protection of Personnel and Plant.

In view of the danger of air attack without warning and of continuing work until the last minute after the alert signal has been received, it is essential that the air raid shelters provided for personnel should be at hand. Wherever possible shelters should be in the form of covered trenches under the floor of the shop with entrances suitably traversed at frequent intervals. Where it is impossible to have the entrances to shelters very close to the place of work, emergency protection must be provided as set out in A.R.P. Memorandum No. 16, "Emergency Protection in Factories."

Where the structure has been designed as described in this Bulletin cover in the form of dwarf walls below benches will provide the worker with satisfactory protection.

The protection of plant is vital and can be provided simply. Individual machines should be protected against blast and splinters wherever possible by traverse walls, at least as high as the machine, and where practicable by a substantial roof.

OBITUARY.

ARTHUR TREVENEN COODE was born in Jersey on the 5th February, 1876, and died at Haslemere, Surrey, on the 28th December, 1940. He was educated privately and at Cambridge University. He served his engineering pupilage under the late Mr. James Mansergh, F.R.S., Past-President Inst. C.E., with whom he was engaged in important works in connexion with the Birmingham water-supply. In 1903 he was appointed assistant engineer on the Folkstone Harbour works, constructed for the South-Eastern Railway under the direction of Messrs. Coode, Son, and Matthews. He was later engaged for that firm, in conjunction with the late Mr. Hugh T. Ker, M. Inst. C.E., upon schemes for sewage outfall works at Plymouth, for harbours of refuge in Devon and Cornwall, and for water-supply in the Fen district. In 1906 he became a partner in the firm, and was intimately concerned with their work as consulting engineers to the Crown Agents for the Colonies. in connexion with harbours, docks, and river works, more particularly in West Africa and in the West Indies. He was also immediately responsible for his firm for the design and construction of a large number of dredgers and ancillary plant supplied to various Colonial Governments through the Crown Agents. During the great war he held the rank of Lieutenant-Commander in the Royal Navy, and served in the Mediterranean and at Archangel. In 1924 he was appointed the British representative on the International Technical Committee of the European representative of the Danube, and served in that capacity until 1938. In 1932 and 1934 he was the British member of International Committees of Engineers dispatched by the League of Nations to China to advise on river conservancy and flood-prevention. He was the author of an article on "Dredgers and Dredging" in the "Encyclopædia Britannica" (14th edition).

Mr. Coode was elected an Associate Member of The Institution on the 2nd December, 1902, and was transferred to the class of Member on the 12th March, 1912.

In 1906 he married Margaret Frederica, daughter of Frederick Gream Ommanney, and had two sons and one daughter.

DAVID LYELL, C.M.G., D.S.O., R.E. (ret.), was born at Gardyne Castle, Guthrie, Scotland, in 1866, and died at Logie, Kirriemuir, Scotland, on the 8th December, 1940. He served his engineering pupilage

on the South London Main Drainage from 1882 to 1885, and then pursued his studies at Edinburgh University until 1888. In May, 1889, he was appointed to the staff of Mr. John Wilson, M. Inst. C.E., at Liverpool Street Station, and in 1891 became resident engineer on the London and Blackwall Railway widening from Fenchurch Street to Stepney. In 1895 he was the representative of the Great Eastern Railway Company on the Lancashire, Derbyshire, and East Coast Railway, under Mr. Wilson, who, in 1898, appointed him assistant in charge of new works on the Great Eastern Railway. From 1900 to 1902 he was on military service in South Africa. Afterwards he did much engineering contracting work in South Africa, and also served with the Transvaal Volunteers. He then worked in South America, Russia, and Canada until 1914. During the great war he was Chief Railway Construction Engineer to the British Army in France, holding the rank of Colonel in the Royal Engineers. He received mention in dispatches and was awarded the D.S.O. in 1917, and the C.M.G. in 1918, whilst other awards included the Order of Leopold of Belgium, the Legion of Honour, the *Croix de Guerre*, and the Order of Aviz of Portugal. During recent years he was managing director of Messrs. Pauling & Co., Ltd., civil engineering contractors, who carried out a number of large harbour and railway contracts in South Africa, and also work in South America and Great Britain.

Col. Lyell was elected an Associate Member of The Institution on the 3rd March, 1892, and was transferred to the class of Member on the 13th February, 1900. In 1920 he presented a Paper[1] entitled "The Work Done by Railway Troops in France during 1914–19," for which he was awarded a Telford gold medal and a Telford premium.

In 1909 he married Kathleen Constance May, daughter of the late Colonel C. J. Briggs, D.L.I., and had two sons.

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[1] Minutes of Proceedings Inst. C.E., vol. ccx (1919–20, part II), p. 94.

ABSTRACTS OF THE CURRENT TECHNICAL LITERATURE OF ENGINEERING AND APPLIED SCIENCE.

ENGINEERING CONSTRUCTION.

A One-Man Curve Ranger. A. M. A. Struben (**J. & Trans. Soc. Engrs.*, 31, *31–34 ; July–Dec. 1940*).—The Author describes a new surveying instrument, used by the Surrey County Council, the main purpose of which is to enable curves for roads, railways, canals, etc., to be set out simply and rapidly by one man instead of by means of a theodolite requiring an observer and two chain-men. The procedure for ranging curves is set out in detail, and various applications of the instrument are illustrated by examples.

The Settlement of Earth Embankments. L. A. Palmer and E. S. Barber (**Public Roads*, 21, *161–166 ; 172 ; Nov. 1940*).—In a report from the Division of Tests, Public Roads Administration, the Authors describe investigations of settlement resulting from the lateral displacement of soil, as distinguished from settlement caused by consolidation. They present the results obtained from stabilometer tests, in which cylindrical soil samples, encased in rubber sleeves, were compressed to complete failure by the application of vertical load. They also discuss the settlement of fill under its own weight, and the settlement of the undersoil. They state that their object has been to shorten the gap between theory and practice by reducing the mathematical work involved in applying the theory ; but the essential requirement is the correlation of field observations with theoretical and laboratory studies, and computed settlements must be elected against observed settlements.

The Fort Peck Slide. T. A. Middlebrooks (**Proc. Am. Soc. Civ. Engrs.*, 66, *1729–1748 ; Dec. 1940*).—The Author describes and discusses tests and analyses carried out in connexion with the slide that occurred at the Fort Peck dam, Montana, on the 22nd September, 1938, when more than 5 million cubic yards—the main mass of the upstream shell—moved out into the reservoir in about 10 minutes (Engng. Abstracts, (Con.), Vol. 2, No. 162 ; July 1939). He draws the following conclusions : (1) the hydraulic fill was not at fault ; it was the general opinion of the

Notes.—An asterisk prefixed to a reference, thus **J. & Trans. Soc. Engrs.*, denotes that the article is illustrated.

The abbreviated titles of periodicals are those used in the " World List of Scientific Periodicals " (Oxford 1934).

investigating engineers and other engineers having an intimate knowledge of the project that the fill material performed excellently even under the most difficult circumstances existing during the slide ; (2) no major changes in soil testing or methods of stability analysis were considered necessary as a result of the slide investigation. Evidently, as the slide did occur, the foundation explorations and investigations, extensive as they were, did not indicate the extent of the weathering in the shale and bentonite seams underlying that part of the dam, or that high hydrostatic pressures would develop in the bentonite seam owing to the superimposed load of the dam. Therefore the major problem in this connexion is always to obtain representative samples of this type of rock, sufficiently large to reveal the true character of the rock to geologists and engineers. Provisions have been made in the reconstruction plans for the Fort Peck dam to observe the hydro-static pressure that develops in the rock and for relieving it where necessary.

Moment-Distribution and the Analysis of a Continuous Truss of Varying Depth. E. R. JACOBSEN (**Engng. Journal*, 23, *502–508 ; Dec. 1941*).—The Paper suggests an adaptation of the Hardy-Cross method for the stress-analysis of a five-span continuous truss of varying depth, and demonstrates that a close approximation to that analysis can be made without reference to the areas of the members. The results are presented fully in Tables.

Plastic Theory of Reinforced Concrete Design. C. S. WHITNEY (**Proc. Amer. Soc. Civ. Engrs.*, 66, *1749–1780 ; Dec. 1940*).—The Author's object is to present a realistic method for the design of reinforced-concrete members that should result in more efficient use of the materials. He proposes the adoption of the plastic theory, which takes into account the plasticity of the material and can be adjusted empirically to actual conditions. It has already been recognized in the adoption of the standard column formula, and the formulas suggested by the Author extend the same theory to beams, eccentrically-loaded columns, and arch ribs. He states that the equations are much simpler than the standard formulas, and agree better with test results : they are based upon the cylinder strength of the concrete and the yield-strength of the steel, without the use of the modular ratio. The new formulas permit the use of more slender members, and will also be beneficial for the haunches of T-beams. The designer will be given more freedom in design and, having simpler tools with which to work, will be able to devote more attention to other important considerations.

Tripole Construction : Support for Heavily-Loaded Transmission-Lines. J. L. GAVEL (**Elect. Rev.*, 128, *203 ; 3 Jan. 1941*).—The Author describes a form of support which, although designed to meet emergency

conditions, is considered to be suitable for adoption also in more normal circumstances. In the poles illustrated each member is made up of two lengths scarfed at the mid-point with iron ring clamps above and below the joint; each is 50 feet long and 11 inches in diameter at a distance of 5 feet from the butt. The line supported is a double-circuit 0·1-square-inch copper 33-kilovolt design incorporating a 7/9 S.W.G. aerial earth wire. At the apex of the tripole the usual key-block and cramping bolts are fitted. At the base two cross baulks with uplift baulks at each extremity are fitted, the middle leg being scarfed to rest between the cross baulks; a through bolt provides the necessary additional support. The third leg assists in withstanding stresses in the line rather than transversely in regard to the foundation of the structure. The Author states that, provided that the three members of the tripole cannot move relatively to one another, the system should provide a means of utilizing short poles of small diameter economically to produce an equivalent high structure of considerable value in overhead line construction.

Lengthening a Railway-Bridge over the Atchafalaya River, Louisiana. H. J. Engel (**Rly. Age, Chicago*, **109**, *946–948; 954; 21 Dec. 1940*).—A detailed description is given of the methods by which a single-track simple-span steel bridge at Klotz Springs, La., has been lengthened by introducing at one end of the existing structure 721 feet of new steelwork consisting of an anchor span and two cantilever arms from which the adjacent simple spans are suspended. A section of the new structure was erected alongside the western end span of the bridge and rolled laterally into position while the existing span was being shifted to one side. This operation was carried out between trains. The displaced span was removed longitudinally to a portion at the opposite end of the new section and reincorporated in the bridge. The remainder of the new steelwork was erected while traffic was carried on a detour track. A special three-well design was adopted for the two new piers required for the cantilever span, the object being partly to facilitate dredging operations where one of the piers was constructed directly under an existing span. The contract price for the project was $723,779.

Behaviour of Concrete Structures in Sea-Water at New York. L. C. Hammond (**Engng. News-Rec.*, **125**, *832–835; 19 Dec. 1940*).—In connexion with the plans and specification for the East River Drive, a study was made to determine the suitability of concrete for exposure to sea-water. Investigations were carried out on nineteen concrete structures in the Hudson, Harlem, and East rivers and in Jamaica bay, built between 1902 and 1932. Some of these structures revealed serious desintegration, but in each case the effects could be attributed to bad construction or design, and the investigations showed that good resistance can be ensured by using a dense concrete, with ample covering of the steel reinforcement,

good workmanship, and protection of the concrete in the tidal range by some form of facing to prevent physical or mechanical damage. Accordingly, concrete was adopted for the structures of the East River Drive, and it is considered that, with the precautions taken in its manufacture, the requirements imposed by the severe conditions will be met.

Pollution of Drinking Water through Cross-Connexion with Fire Lines. J. C. GEIGER (*J. Amer. Waterw. Ass.*, 32, *2006–2013; Dec. 1940*).—On the 24th August, 1940, a large fire occurred on "Treasure Island," the site of the Golden Gate International Exhibition, San Francisco, and heavy demands were made upon the water-supply, which had been arranged in two distinct sections, for domestic and fire-fighting purposes respectively. Despite protests made by the Department of Public Health, four cross-connexions between these supplies had been established, three being manually-operated gate valves in duplicate and the fourth a check valve and gate valves. During the fire, as had been feared, failure to close all of the valves resulted in pollution of the drinking-water supply by salt water from the bay. Portable chlorinators were brought into operation, and within 15 hours the domestic supply was restored to a safe, potable condition.

Treatment of the Delaware Water-Supply to New York City. (**Engng. News. Rev.*, 125, *822–826; 19 Dec. 1940.*)—The water from the new Delaware supply, like that from the Croton and the Catskill systems, is of such good quality and so carefully safeguarded that filtration is considered to be unnecessary. The various precautions, which are described in detail, include constant inspection and sanitation of the watersheds, long storage periods in the reservoirs, which have an available capacity of about 232 million gallons, clarification with alum and lime, multiple chlorination, and continuous laboratory control, involving more than 30,000 analyses per annum.

MECHANICAL ENGINEERING.

Producer-Gas Tests in the Queensland Railway Department. C. RENTON (**J. Instn. Engrs. Australia*, 12, *274–278; Oct. 1940*).—The Author describes tests made on a French cross-draught type of producer, designed for charcoal fuel, which was fitted to a 45-horse-power goods rail-car. Three return-trips were made over a stretch of the line 27·037 miles in length, with ½-minute stops at eight intermediate stations to represent service conditions and also to allow a greater number of acceleration tests to be observed. The results are plotted in graphs, whilst fuel-consumption and cost data are tabulated.

War Damage to Electric Supply Mains. W. E. BRADSHAW (*Elect. Rev.*, 128, *226; 10 Jan. 1941*).—The Author describes how cables

of all varieties, from 11-kilovolt feeders to 200–400-volt distributors, have withstood aerial attack; thus an 11-kilovolt three-core cable was still carrying load although it had disappeared owing to the collapse of the crater-edge and was many feet below its correct level. He gives advice on the repair of damage, and emphasizes the value of keeping careful records of the joining together of colours in making joints. He states that a new cable must be of the same length, and have the same "lay" as the cable it replaces: it is necessary to know which colours must be connected together, and to see that that is done. In laying a greater length than the damaged portion the jointing will be simplified if care is taken that the rotation of colours in the new cable is the same as in the old: if that is not done, it may be necessary to cross over two cores in a joint—which is inadvisable—or to change over the tails at the switchboard, which in some cases is very awkward.

A Pond Water-Spray System for Fighting Sub-Station Fires. P. J. Zeibe (**Elec. World*, 114, *1170–1771; 14 Dec. 1940*).—The Author describes the system installed for the fire protection of three banks of 66/13-kilovolt transformers at the Newlinville substation of the Philadelphia Electric Company. As the nearest water-supply was 1,600 feet away, a pond of 50,000 gallons capacity was formed near to the plant, and two 750-gallon-per-minute fire pumps, each driven by a 95-horsepower petrol engine, were installed to supply water at a pressure of 90 lb. per square inch. During a test it was found that 15 seconds after the single operator received the call he had the fire pumps in operation, whilst 45 seconds later full spray was being directed on the transformer. Connexions have been provided to enable the local fire-fighting organizations to furnish water from the distant supply in case of failure of the system through lack of water in the pond.

MINING ENGINEERING.

Properties of Coal Surfaces. G. A. Brady and A. W. Gauger (**Ind. Eng. Chem.*, 32, *1599–1604; Dec. 1940*).—Among the properties of coal surfaces that are of scientific and practical importance, the wetting characteristics are particularly valuable in the selective flotation of coal components and the separation of coal particles from liquids. One phase of this problem involves the degree of wetting, that is, the extent to which a given liquid will spontaneously wet a solid surface. The extent to which such action takes place may be quantitatively expressed in terms of the angle of contact. The Authors review various methods of measuring contact angles, and discuss their applicability to a study of the wetting characteristics of coal surfaces. They describe experimental measurements of contact and interfacial angles in the two systems, coal–liquid–gas and coal–organic liquid–water. The contact angles of small air-bubbles on a

bituminous coal surface immersed in water are tabulated. A bibliography of the subject is appended to the article.

Faulting and Ground Movement at the Wright-Hargreaves Mine. H. HOPKINS (**Canad. Min. Metall. Bull.* (*Trans. Sect.*), *685–707 ; Nov. 1940*).—The effects on mining exercised by the faults met with locally were studied on account of the occurence of rockbursts in the neighbouring mines. Fault intersections in drifts and cross-cuts were examined microscopically in order to determine whether tectonic movements might still be in action. Some hundreds of intersections were examined, but only a few showed signs of movement, and this was definitely connected with the process of excavation. Various forms of ground movement are illustrated, and the resultant phenomena are discussed.

The Development and Construction of Longwall Roadways. H. C. M. GORDON (**Canad. Min. Metall. Bull* (*Trans. Sect.*), *657–668 ; Nov. 1940*).—Owing to the tendency of the goaf to thrust downhill, even in slightly-inclined seams, with consequent displacement into the roadway of the high-side ribs and packs, and to the probability of the roof breaking along a line of rigid packs, a system of double packing of the roadways is being tested in Nova Scotia. The immediate roadside packs are constructed in the usual manner, but are not more than 9 feet in width. These are followed by an unsupported gap of 9 feet, which, in turn, is followed by a very rigidly built pack at least 17 feet in width. The roof breaks along this latter pack on either side of the roadway, and is allowed to fall in the unsupported gap. As a result the stresses in the vicinity of the roadway are relieved and settlement of the strata over the road is much more uniform than where single packing is used. The Author states that the immediate roadside pack, whilst firmly built, should be less rigid than the one on the other side of the gap. Double packing shifts the line of shear away from the roadside.

Preparation of Sand and Clay Stemming at Collieries. H. STAFFORD and F. S. ATKINSON (*Trans. Instn. Min. Engrs.*, 100, *44–52 ; Dec. 1940*).—The Authors present the results of tests carried out with various types of stemming materials, under standard conditions, in a limestone quarry over a period of several years, which enable comparisons to be made of their efficiencies with those of dry and wet clay. They state that probably the best proportion consists of 3 parts of sand and 1 part of clay. The machines used for making sand and clay stemming are classified as (1) the concrete-mixer type ; (2) the mortar-mill type ; (3) the bread-making or cordite-mixer type ; each is described in detail. The Authors conclude that good stemming results in safer blasting practice and more efficient use of explosives, and that it is well worth ensuring that the supply of stemming is consistently good.

A Technique for Blasting with Detonating Fuse. P. C. Ziemke (**Engng. & Min. J.*, 141, (*12*), *48–51 ; Dec. 1940*).—The Author observes that as about 100 million lb. of explosives is used annually in quarry operations alone in the United States, the cost of explosives forms an important part of the operating expense : the cost of explosive per ton of material produced ranges from 8 to 15 per cent. of the total, and is exceeded only by the cost of labour and drilling. Economies in the use of explosives are frequently possible. The method best suited to drilling an individual shot must be determined by the character of the stone, the thickness of the vein, its stratification, the type of equipment available, and the purpose for which the material is to be used. The Author discusses the development of the well-drill method, and the spacing of well-drill holes, the required depths of sub-drilling for faces of average heights ranging from 30 feet to 200 feet. He also discusses the estimation of the charge, and suggests an allowance of 1 lb. of explosive to every 3 to 6 tons of material. He describes the Cordeau and Primacord fuses, and methods of connecting them to the charges of explosive, and emphasizes the necessity for a combination of caution, patience, and care in the conduct of the blasting operations, and in the handling and transport of explosives.

A Barvoys Washery at a Midland Colliery. (**Iron Coal Tr. Rev.*, 142, *31–32 ; 10 Jan. 1941.*)—The plant described is designed to heat 100 tons of coal per hour, with a peak load of 120 tons per hour when dealing with raw coal from 3½ inches to ⅞ inch in size. The scheme of operation provides for three-product separation in a single Barvoys bath, filled with a medium of specific gravity 1·30, and with middlings extraction equipment. The coal is divided into three fractions, namely, clean coal floating at 1·30 ; middlings having a specific-gravity range between 1·30 and about 1·55 ; and shale sinking at about 1·55. Provision is also made for crushing the middlings to 1½ inch or less ; this is then screened to remove all below ⅞ inch, the oversize being returned to the raw-coal feed and the through material collected separately. Operating results are given.

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NOTE.—*Pages* [1] *to* [8] *can be omitted when the Journal is bound in volume form.*

NOTICES

No. 5, 1940—41

MARCH, 1941

MEETINGS, SESSION 1940–41.

ORDINARY MEETINGS.

The following subjects will be brought forward for discussion at Ordinary Meetings, on the date shown below :—

1941.
Mar. 18.* (1.30 p.m.) "**Aesthetics of Engineering Structures**", by Oscar Faber, O.B.E., D.C.L., D.Sc., M. Inst. C.E.

and

"**The Design of Flour Mills, Granaries, Warehouses and Silos**", by Oscar Faber, O.B.E., D.C.L., D.Sc., M. Inst. C.E.

There will be a ballot for the election of new members.

* Abstracts of the Papers appeared at pp. [9] and [10] of the February Journal.

(*Light refreshments will be served at* 12.30 *p.m.*)

ROAD ENGINEERING SECTION.

The attention of members is particularly directed to a meeting of the Section to be held at the Institution on Tuesday, 22 April, at 5 p.m., when Mr. A. J. H. Clayton, B.Sc. (Eng.), Assoc. M. Inst. C.E., will introduce for discussion the following Paper :—

"**Road Traffic Calculations.**"

A brief synopsis appears on p. [7] *post*, and advance proofs may be obtained upon application to the Secretary. It is not practicable, under present conditions, to send individual notice of the meeting by post to members of the Section, and it is, therefore, hoped that the above announcement will be carefully noted.

(*Light refreshments will be served at* 4.30 *p.m.*)

JAMES FORREST LECTURE.

Referring to the announcement printed on p. [1] of the February Journal, Dr. C. G. Darwin, M.C., M.A., F.R.S., now finds that he cannot deliver the Lecture in the present Session.

The Council are glad, however, to be able to announce that Professor E. N. da C. Andrade, D.Sc., Ph.D., F.R.S., has consented to be the lecturer for this Session and will take for his subject " The Mechanical Behaviour of Solids."

The date of the lecture has been fixed for Tuesday, 29 April, at 1.30 p.m.

There will be a ballot for the election of new members.

ANNUAL GENERAL MEETING.

The Annual General Meeting of Corporate Members will be held on Tuesday, 27 May, at 1.30 p.m.

The meeting will be preceded by a ballot for the election of new members.

SPECIAL ANNOUNCEMENTS.

INSTITUTION LUNCHEON.

Arrangements have been made to hold a luncheon at Grosvenor House, Park Lane, W., on Wednesday, 30 April. Particulars are given on the accompanying leaflet issued to home Corporate Members and Associates. The Right Hon. Baron Reith of Stonehaven, P.C., G.C.V.O., G.B.E., M.Inst. C.E., Minister of Works and Buildings, will be the principal guest.

RECORD OF SERVICE IN THE FORCES.

For office purposes, a record is being kept of members' service with H.M. Forces, and members who have not already done so are asked to inform the Secretary of such service, i.e. unit, rank, promotions, decorations, etc. Further, practical use is made of such information when inquiries from the Services are received by The Institution.

MILITARY SERVICE. MINISTRY OF LABOUR.

Details of the following appear on pp. [2]–[5] respectively of the December, 1940, Number of the Journal :—

Vocational instruction for those temporarily serving in H.M. Forces (p. [2]).

Registration in the Army Officers' Emergency Reserve, and special enlistment in the Royal Engineers (p. [4]).

An entry in the Ministry of Labour's Schedule of Reserved Occupations as affecting " student engineering apprentices or learners ", reserved at and above the age of 18 years, who wish to sit for Sections A and B of the Associate Membership Examinations, together with information as to the

procedure to be adopted by Corporate Members of The Institution who are required to register at Local Employment Exchanges when their age-groups are called up under the National Service (Armed Forces) Act, 1939 (p. [5]).

NATIONAL SERVICE (ARMED FORCES) ACT, 1939.

Students of The Institution who are above 18 years of age and who are liable for Service under the National Service (Armed Forces) Act, 1939, must register at a Local Employment Exchange when their age-groups are called, and may obtain from the Secretary a form of certificate indicating their connexion with The Institution, which, upon production to the Registration Officer, will, it is anticipated, assist them in being posted to the ranks of the Corps of Royal Engineers or to a technical unit in which their qualifications can be employed.

ROYAL MARINE ENGINEERS. AIR MINISTRY.

Particulars of vacancies in the Corps of Royal Marine Engineers and in the Royal Air Force Volunteer Reserve appear at pp. [2] and [3] respectively of the February Number of the Journal.

GENERAL ANNOUNCEMENTS.

THE JOURNAL.

The next Number of the Journal will be published on the 30th April.

INVITATION TO PRESENT SHORT PAPERS.

The Council are prepared to receive short original Communications of, say, 2,000 words, accompanied by two or three illustrations, for inclusion in the Journal. Such Communications should be topical in character and might deal, for example, with demolition and reconstruction problems, or with minor constructional details, of a novel character, which would be of general interest to engineers.

"INGENUITY" COMPETITION.

Papers are invited from Corporate Members and Students in competition for a Prize of Twenty-five Guineas to be awarded by the Council for a description of an engineering problem and the method adopted to solve it.

The article should not exceed 2,000 words, and must describe a specific problem involving immediate action and ingenuity displayed in meeting it. The problem must have arisen in the competitor's own experience, and the

action taken must have been to some extent—not necessarily wholly—his own idea. These facts must be vouched for in a satisfactory manner.

The Papers should reach the Institution by the 30th April, 1941, with the MS. marked " Ingenuity " Competition in the top left-hand corner of the first page.

The Council reserve the right to publish the winning entry, or any other selected entries, and should such entries relate to engineering problems arising out of the war, The Institution would submit them to the Censor for permission to publish.

HONOURS.

The Council have much pleasure in congratulating the following Corporate Member on the Distinction conferred upon him :—

George Medal.

LEE, Ralph Henry, B.Sc. *Associate Member.*

" For conspicuous gallantry in carrying out hazardous work in a very brave manner."

TRANSFERS, ELECTIONS, AND ADMISSIONS.

Since the 21st January, 1941, the following elections have taken place :—

Meeting.	*Associate Members.*
18 February, 1941.	18

and during the same period the Council have transferred four Associate Members to the Class of Members, and have admitted twenty-nine Students.

DEATHS AND RESIGNATIONS.

The Council have received, with regret, intimation of the following deaths and resignations :—

DEATHS.

BATLEY, Charles Joseph. (E. 1887. T. 1906.)	*Member.*
BROWN, James, C.B.E. (E. 1917.)	"
COPP, Harold Ernest. (E. 1921.)	"
DICKINSON, Alfred. (E. 1889. T. 1903.)	"
HAIGH, *Professor* Bernard Parker, M.B.E., D.Sc. (E. 1911. T. 1922.)	"
HELE-SHAW, Henry Selby, D.Sc., D.Eng., LL.D., F.R.S. (E. 1880. T. 1887.)	"
MANTON, Arthur Woodroffe, O.B.E., B.Sc. (E. 1891. T. 1899.)	"
MAY, Walter Edward. (E. 1890. T. 1908.)	"
PERRY, William Richard Victor Prittie, B.A., M.A.I. (E. 1898. T. 1906.)	"

Taylor, Edward Brough. (E. 1881. T. 1890.)	*Member.*
Trump, John, I.S.O. (E. 1883. T. 1896.)	„
Whitcombe, Charles Palmer. (E. 1879. T. 1892.)	„
Willcox, Joseph Edward. (E. 1883. T. 1905.)	„
Baird, James Alexander. (E. 1908.)	*Associate Member.*
Broadhead, Sydney William Voddon, B.Sc. (E. 1913.)	„ „
Campbell, James Maclachlan. (E. 1916.)	„ „
Cruickshank, William Donald McDonald, O.B.E. (E. 1911.)	„ „
Maclennan, Duncan Thomas Hiddleston. (E. 1922.)	„ „
Marrable, William Reginald. (E. 1933.)	„ „
Parry, Edward. (E. 1922.)	„ „
Raper, John Charles Dodgson. (E. 1892.)	„ „
Richards, Charles Sydney, B.Sch.Tech. (E. 1910.)	„ „
Toplis, Frederick. (E. 1873.)	„ „
*Mason, John Victor Coulson. (A. 1938.)	*Student.*

* *Killed on Active Service.*

Resignations.

Fraser, Thomas. (E. 1903.)	*Associate Member.*
Wilson, James Bruce, B.Sc., B.E. (A. 1937.)	*Student.*

RECENT ADDITIONS TO THE LIBRARY.

[Journals, Proceedings of Societies, etc., are not included.]

Bridges. Emmen, J. "Gewapend Beton en Ijzer in den Brugbouw." 1934. Amsterdam. No price.

—— Indian Railway Board. "20th Report of the Bridge Standards Committee." 1940. Calcutta. East Indian Railway Press. No price.

Bronze. Dews, H. C. "Metallurgy of Bronze." 1930. Pitman. 12*s*. 6*d*.

Chemical Engineering. Tongue, H. "Practical Manual of Chemical Engineering." 1939. Chapman & Hall. 40*s*.

*Concrete. Faber, O., and Childe, H. L. "Concrete Year Book, 1941." 1941. Concrete Publications, Ltd. 4*s*. 6*d*.

Engineering. Portway, D. "Examples in Elementary Engineering." 1937. Cambridge Univ. Press. 5*s*.

Engineering Economics. Burnham, T. H., and Hoskins, G. O. "Engineering Economics." Book 1. 5th ed. 1940. Pitman. 10*s*. 6*d*.

Gases. Ruhemann, M. "The Separation of Gases." 1940. Clarendon Press. 21*s*.

*Hydraulics. Lacey, G. "Regime Flow in Incoherent Alluvium." 1939. Central Board of Irrigation, India, Publication No. 20. No price.

Lettering. Evetts, L. C. "Roman Lettering." 1938. Pitman. 7*s*. 6*d*.

*London. Reddaway, T. F. "The Rebuilding of London after the Great Fire." 1940. Cape. 18*s*.

Petroleum. De Golyer, E., *Ed*. "Elements of the Petroleum Industry." 1940. New York. Am. Inst. Min. & Met. Engrs. 30*s*.

Roads and Streets. Gillette, H. P., and Black, J. C. "Road and Street Construction: Methods and Costs." 1940. Chicago. Gillette Pub'g Co. 33*s*.

*—— Picher, R. H. "Stabilized Roads." (Canada Bureau of Mines Publication No. 800.) 1940. Ottawa. Govt. Printer. 25c.

*SEDIMENTATION. HAPP, S. C., and others. "Some Principles of Accelerated Stream and Valley Sedimentation." (U.S. Dept. Agric. Technical Bull. No. 695.) 1940. Washington. Supt. of Documents. 75 cents.

STRUCTURES. STEWART, D. S. "Practical Design of Simple Steel Structures." Vol. 2. 2nd ed. 1940. Constable. 16*s*.

SURVEYING. CLARK, D. "Plane and Geodetic Surveying." Vol. 1. 3rd. 1940. Constable. 27*s*. 6*d*.

TUNNELS. ASH, S. H. "Safety Factors in Construction and Ventilation, Wawona Vehicular Tunnel, Yosemite Park, California." (U.S. Bureau of Mines Technical Paper No. 608.) 1940. Washington. Supt. of Documents. 20 cents.

(* *The foregoing books, with the exception of those marked with an asterisk, may be borrowed from the Loan Library.*)

ROAD ENGINEERING SECTION.

Synopsis of Paper on

"Road Traffic Calculations."

By A. J. H. Clayton, B.Sc. (Eng.), Assoc. M. Inst. C.E.

Date of Discussion 22/4/41 (5 p.m.)

The Paper is intended to summarize the present position on the subject, with a view to affording a basis for discussion. After reference to the need for quantitative methods in dealing with traffic movement and control, it discusses the basic problem of the capacity of a single traffic lane.

The calculation of the capacity of street intersections and the delays experienced thereat is dealt with, as well as the use of calculation in the design and adjustment of traffic-control signal installations. The Paper explains briefly how the effect of revised traffic arrangements can be foreseen with a practical degree of accuracy, and deals with the use of traffic calculations in the design of road improvements and the estimation of the economic advantages of alternative schemes.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH.

Emergency Pipe Repairs.

The standard peace-time method of jointing water-mains and gas-mains, which uses lead in one form or other, is a skilled and tedious operation. The shortage of skilled pipe-jointers and the time taken by the operation, may cause serious delays in restoring services interrupted by enemy action. It is important as a defence measure, possibly a primary one, to be able to use any alternative methods of jointing that are available and take less time. Wartime Building Bulletin No. 12—Emergency Pipe Repairs—(H.M. Stationery Office, price 6*d.*), which has been issued by the Building Research Station of the Department of Scientific and Industrial Research, contains details of these methods.

The alternatives available are of two main types: those which are fully mechanical, and those which employ plastic or liquid caulking materials.

The *mechanical methods* form an important group. In all of them, rubber rings are compressed in various ways to form the seal. The joints are quickly made and are not only flexible (a very important point since some settlement of newly filled ground must be expected), but so simple that operatives can learn the technique of even the most complex joints in a day or two, at most. Moreover, the joints can be made when conditions are unfavourable.

The *plastic fillings*, also, have the advantage of being quick; and they require no heat. Moreover they can be applied to a pipe which is not dry and cannot be dried, which is important. The main drawback of the technique is that a little time is required for the joint to harden, and during this period it has to be protected. On the other hand, the work can be done by bricklayers and plasterers when trained pipe-jointers are lacking.

The *poured fillings* in this second group of alternatives have certain disadvantages for emergency repairs which may often make them unsuitable. For instance they have to be melted and poured into the joint cavity, which must be dry. But once the joint is run and has cooled, it comes to full strength, and the service can be restored forthwith. For this reason alone poured fillings merit attention in emergency repair technique.

A full description of all the proprietary methods of jointing is given in the bulletin, and the time taken to carry out typical repairs is indicated.